THE UNIVERSITY OF ALBERTA

EVALUATING DRAINAGE PROBLEMS ON SOME SOUTHERN ALBERTA SOILS UNDER IRRIGATION

by

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A THESIS

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ABSTRACT

Four drainage investigation techniques were developed for evaluating drainage problems on some southern Alberta soils under irrigation. Two methods were interpretative while the other two were empirical. The interpretative methods used the soil survey report and aerial photographs to evaluate the drainage problem of the area. The empirical techniques examined the area from two different points of view. The empirical drainage classification, based on the Storie-Index, used only four selected characteristics related to the drainage of water in the soil. The water table classification described by four physical factors and a modification factor made use of observation well records. In order to use this water table classification, a statistical method was developed for summarizing the water table data.

The four drainage investigation techniques were evaluated and applied to two areas in southern Alberta. The conclusions from each method were combined to produce an overall drainage rating of the area. The soils that presented some problems were the Cavendish loamy sand and the Coaldale silty clay loams. The problem sometimes was due to location rather than soil type as was the case in the Lethbridge loams. No generalization could be made from this since only two small areas were studied.

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Chapter 1

INTRODUCTION

Upsetting the hydrology of an area by adding irrigation water sometimes results in drainage problems. Many unsatisfactory irrigation projects exist due to lack of understanding of soils, engineering design or poor maintenance. These misunderstandings could cause severe drainage problems which can be avoided. Knowing the problem exists and why this problem exists will benefit both the farmer and the consumer. An expensive subsurface drainage system is not always necessary since usually the drainage problem is due to poor management and lack of foresight.

Rather than concentrating on surface and subsurface drainage, the procedure to follow is firstly to evaluate the drainage problem and then to solve the problem. Evaluating a drainage problem requires an accumulation of pertinent data and then analyzing this data. Solving a particular local drainage problem from a general drainage map results in incorrect assumptions and therefore should be avoided.

The methods to be used in evaluating a drainage problem should be adapted to the area. Certain peculiarities exist in southern Alberta, such as the nearly impermeable glacial till. These characteristics must be considered. The data that was obtained from various agencies are listed below:

1. Soil survey report for the area,
2. Geologic report for the area,
3. Aerial photographs of the area,
4. Observation well records,
5. Local weather information,
6. Irrigation district annual reports,
7. Studies and other reports on the area,
8. Personal interviews.

The object of the study was to utilize this data and to develop some methods to evaluate drainage problems. Each method would examine the drainage problem from different points of view. These methods are then applied to two selected areas in southern Alberta.

The procedure reads as follows:

1. To utilize aerial photograph interpretation in assessing a drainage problem;
2. To utilize the soil survey report soil description to assess a drainage problem;
3. To develop an empirical drainage classification for assessing a drainage problem;
4. To develop a water table classification for the areas;
5. To apply all these methods to two areas and then compare each method to obtain a final assessment of the drainage problem.

These are the major steps followed in this study and are futher investigated in the next chapters.

Chapter 2

REVIEW OF LITERATURE

Evidence of drainage problems must be present before initiating a drainage feasibility study. In semi-arid areas, such as exist in southern Alberta, irrigation is necessary since only in one of two years is there sufficient rainfall during the growing season. The irrigation water applied sometimes causes drainage problems on certain soils. In order to establish and predict the natural drainage performance of soils under irrigated conditions, approaching the problem, analysing the available data, utilizing this data and developing new drainage guides are among the essential parts of such a study. These topics are further investigated in the literature presented hereafter. Any additional references will be cited in later chapters.

2.1 History and Evidence of Drainage Problems in Irrigated Areas

2.1.1 Around the world

The problem of drainage has long followed the history of irrigation. From early history records of irrigation, Means (1930) reported that drainage problems have always been important and lack of drainage has been a factor in many historical events. The valley of the Tigris and Euphrates River in ancient Mesopotamia has largely returned to desert. At one time nearly ten million acres of land in ancient Chaldea were, to quote the late Sir William Willcocks, as "fertile as a garden". Lack of drainage in this part of the

region has contributed to areas which now consist of alkali flats and saline areas. In regions of Arabia and the Sahara Desert, remains of abandoned irrigation works, saline areas, salt-marsh areas and fields are indications of past drainage problems. In India, drainage problems were threatening to ruin many irrigation projects established by the British. In America, in the Salt River Valley in Arizona, ancient irrigators must have been troubled with alkali, since the accumulation of alkali along the old ditches has been found in many places.

2.1.2 In the United States

In the San Joaquin Valley of California, irrigation started in the 1850's. Weir (1954) mentions that Hilgard, renowned Soil Scientist, in 1886 called attention to the need for drainage and alkali reclamation in the San Joaquin Valley. Before irrigation existed in the region, the ground water table varied between 40 to 80 feet below the surface, but after increasing the irrigated acreage and the lavish use of water, the water table rose within range of the root zone. By 1913, practically all the irrigated lands in the San Joaquin Valley were threatened with abandonment. Berry and Stetson (1959) reveal that the rapid growth resulted in developments, sometimes unco-ordinated, which caused serious problems. Many of these problems have been solved but probably the most puzzling of the remaining and unsolved problems are those of drainage.

Also, in the State of California, the Coachella

Valley is an intensely irrigated area. Weeks (1959) indicates that before the source of irrigation water was from the Colorado River, the problem of drainage was not important. This new supply of water from the Colorado River with a heavy content of total salts would change irrigation practices, and the water table would rise, thus causing serious drainage difficulties in the future.

In studying the drainage problems of the Lajas Valley, Puerto Rico, Willardson (1958) concluded that there was evidence, from the piezometer readings, of an upward movement of the water table in some irrigated areas. The basis of this study was to anticipate drainage problems before they became too serious.

Nelson (1963), in the Quincy area of the Columbia Basin project, Idaho, has reported that after three seasons of irrigation from 1952-1954, the water table depths decreased from a range of 130 to 230 feet, to a range of 10 to 75 feet. The heavy application of irrigation water, accompanied by poor drainage conditions, resulted in a considerable increase in water table height.

2.1.3 <u>In Alberta</u>

In Alberta, evidence of drainage problems were mentioned in various soil survey reports. In the soil survey report of the Medicine Hat Sheet (Wyatt and Newton 1926), the authors report that some problems will arise in connection with future developments of irrigation. Even if the soils absorb water freely and possess a rather high water

holding capacity, over-irrigation and alkali will cause some difficulty.

In the soil survey report of the Lethbridge-Pincher Creek Sheets (Wyatt et al 1939), the authors recognized that certain soil types do not respond equally to the application of irrigation water; therefore, different soils require different management. Before initiating a project, the drainage and alkali problems of the area should be assessed and necessary steps taken to prevent the ruination of productive land.

In a later report submitted to the Alberta government, Hanson et al (1958) indicated that the problem of damage to land due to waterlogging and accumulation of salts from seepage was encountered in all established districts. Most irrigationists recognized that "drainage is as much an essential part of an irrigation system as the canals." Maierhoffer (1958) said that drainage is an integral part of the development of a permanent irrigation agriculture. Studying drainage problems to avoid damage to more land must be given high priority.

Milne and Sadler report, in Appendix II of the Soil Survey (Bowser et al 1963) of the St. Mary River Irrigation Development (S.M.R.I.D.), that water table fluctuations were recorded under various soil types, such as the Cavendish series and Chin series. In the Coaldale series, a finer textured soil, the water table remained at 19 feet. The sites that were being considered were under

intensely irrigated areas. Some soil types are rated poor to fair for irrigation. Therefore, to effectively prevent any drainage problem, emphasis should be on an accurate land classification, good irrigation practices, proper land preparation, and the maintenance of good surface drainage.

2.2 The Drainage Investigation Technique

There is much published literature on drainage investigation methods in irrigated areas. Only a few are cited such as Milne and Rapp (1968), Maughan et al (1949), and Gardner and Israelsen (1954). Essentially, they all follow similar procedures.

2.2.1 Planning a drainage project

Chow (1964) attacks the planning of a drainage project by answering many important questions. What is the source of the excess water? Can this excess water be removed from the soil? What quantity of water should be drained? Does the drainage project possess an outlet for the drainage outlet? How should the project be drained? What type of system should be used? Reviewing all available data for the problem area is necessary even if the planning is on a small scale. Geologic reports, previous surveys or plans, and engineering publications are all useful tools. Field reconnaissance is needed to obtain further knowledge on the required investigation, and topographic maps, soil surveys and water table surveys are usually needed.

The feasibility of a drainage project plays an important part in making the decision, especially if economics

are involved. Myers (1960) states that, to evaluate the feasibility of a drainage project, four important considerations are involved.

1. The soils and crops grown in the area should provide a basis for selecting suitable drainage methods.

2. Interpretation of soils data, physical land attributes and agronomic factors should supply additional information on drainage requirements.

3. Various means of controlling the water table must also be included in order to determine the drainage feasibility of the project.

4. An economic evaluation (cost-benefit ratio) must also be done on the drainage feasibility of the project.

In the final analysis, a drainage guide can be formulated and should include recommendations for handling irrigation and drainage problems.

When approaching the various considerations presented above, a drainage investigation guide is necessary. Winger and Luthin (1966) in their guide for drainage investigations mention that two investigations are possible; the first being a reconnaissance investigation which requires little field work, and the second is a detailed investigation which includes field work, laboratory analysis, and a great deal of co-operation with related fields of study. Donnan and Bradshaw (1952) complement the previously described drainage investigation guide. A detailed drainage investigation is undertaken firstly as a preliminary investigation, secondly

as a ground surface investigation, thirdly as a soil investigation, followed fourthly,by a water table investigation. Utilizing the available data and new field data, information is gathered and investigated in order to submit a comprehensive report of the drainage problem.

Reger et al (1950) also conducted a drainage investigation in the Coachella Valley, California. The investigation was started before any irrigation existed in the region which makes this study unique. The investigation that was conducted dealt mainly with the changes in elevation, the movement and the source of the water table.

2.2.2 Data gathering and analysis

The drainage investigation approach involves gathering the appropriate data and then analysing this data. A choice has to be made as to what is important and what is not. For the study conducted in this thesis, the selection of data was limited to what was available. The most accurate data available was from the Alberta Department of the Environment, which consisted of observation well records, aerial photographs, published and unpublished reports concerning soil drainage and other useful maps. The irrigation districts, Taber Irrigation District (T.I.D.) and S.M.R.I.D., provided water delivery records, but their usefulness has not yet been evaluated. The soils map for the areas to be studied is fairly recent and provides additional useful information concerning the soil characteristics.

Geologic considerations should not be ignored; there-

fore some information was obtained relating to the geology of the area. Additional information on the MacLaine Drainage Basin of the S.M.R.I.D. is provided by Nielsen (1968, '69, '70, '71a, '71b), when conducting an irrigation study for the International Hydrological Decade.

Water table investigations

Approaching the analysis of data involved a considerable amount of literature review. Work that was done relating water table fluctuations to the drainability of the soil was investigated. Myers and van Bavel (1963) report that the significance of water table measurements is often limited and should be carefully evaluated. There is no apparent simple relation between the water table and the degree of saturation of the soil profile. Similarly, relating water table elevation to crop growth is very difficult and sometimes impossible.

Hiler (1969) lists some of the possibilities for a drainage design criterion, stating that a water table is not always the best parameter to use. A water table can be declining, fluctuating, or at a static level. For an irrigation district where drainage is important, a fluctuating water table provides the best available characterization of the physical situation in the field.

Rapp and van Schaik (1971) observed that the water table fluctuation on glacial till soils was mostly due to irrigation and precipitation. Water table recession was mostly influenced by two factors: consumptive use of the

crop and downward movement of the water. By monitoring the water table continuously from two to four years, probability levels of water table depths were determined along with recession rates. No long-term evaluation could be given due to the short period of record.

When considering an irrigation project, predictions of drainage behaviour are more useful if made on a long-term basis. Rapp and van Schaik (1972) used a 15-year record of observation well readings in the Vauxhall district of the Bow River Project to investigate long-term trends of water table depths. No consistent relationship seemed to exist between seasonal water table depth and total water available. In some cases, seasonal rainfall influenced the water table more than the irrigation water delivered.

Statistical investigations

The investigations that were undertaken by the previous authors did not include any predictions. Statistical hydrology is becoming a new useful tool. By using such techniques, Pierce and Vogt (1953) developed a method for predicting lake level fluctuations. Recording the monthly high, low, and the difference, was the first step, which was followed by determining the distribution. All were normally distributed. By plotting high values against low values on Cartesian co-ordinate paper, and fitting a straight line, confidence limits were then constructed in order to predict one value from the other. Orsborn (1966) noticed that this technique could be used in predicting

water table depth from prior occurrences. He used the maximum water table depth, the minimum water table depth, and their difference. Since the maximum depth and minimum depth were highly correlated, good predictive values were obtained.

Another statistical method used for analysing hydrologic data is a time series analysis. The technique can be used on the water table data if the readings are taken at an equal interval of time. Chow (1964) and Rigs (1969) provide brief descriptions of this method. Yevjevich (1972) dedicates one whole chapter on autocorrelation as a method for investigating hydrologic processes. He says that nearly all hydrologic time series of daily and monthly values have deterministic components which are periodic series. The correlogram,which is the serial correlation coefficients plotted against time lag, is then examined and certain conclusions are made concerning the hydrologic series.

Other investigations

Other methods of analysis were used to study drainage problems using water table readings. In 'Drainage of Agricultural Land' (U.S.D.A. 1972), groundwater contour maps, depth-to-water-table maps and ground surface topography maps are all used to delineate drainage problems in a given irrigated area. Seasonal minimum water table-depth maps are used to further indicate a high water table area. Observation well hydrographs are compared. McCracken (1966) utilizes all of these techniques in his drainage study of an

irrigation district of California.

Most of the literature has concentrated on the techniques and usefullness of using water table information since it was the only reliable hydrological parameter besides precipitation records. The soils, not being a hydrological parameter, will be further investigated in the section on land classification. Evaluating water table data is impossible if all other factors are neglected. Yet, trends, predictions and actual readings of water table will produce some valuable information. Future problems can be located as was indicated by Rapp and van Schaik (1972). Similarly, water table information is used in order to evaluate possible oncoming problems in the irrigation districts of Alberta (McCracken 1973).

2.3 Land Classification and Land Use Approach

In an irrigated area, there are a variety of soil types which possess different characteristics along with other factors, such as water table depth, irrigation system used, topography, climate and also crops grown. Since the agricultural capacity of soils in irrigated areas will depend greatly on the soil drainability, the land could be classified according to its drainage potential (Fly 1961). This way of approaching the problem would be a specialized land classification. Instead of using simply agriculture or recreation or wildlife production as a means of classifying or evaluating land, certain well-chosen drainage characteristics could be used in an attempt to evaluate the irrigation

agricultural capability along with the other possible capabilities of the land.

2.3.1 Definitions

Williams (1972) defines land use planning as a method by which a selection of land areas that have a high, natural potential for development for one or more resources, is made and then planned for development according to their best possible use. For an irrigated area the potential has always been traditionally agriculture first, and then any other secondary use. Evaluating the different possible capabilities or potentials of the land has become an interesting topic. Stewart (1968) says that land evaluation is an assessment of man's possible use of land for any purpose. Using the parametric approach described by Mabbutt (in Stewart 1968), which divides and classifies land on the basis of selected attribute values, an assessment of the land can be made. For a drainage problem, the choice of attributes and attribute values can be based on the use of water table fluctuation as the parameter. In assessing drainage situations and assigning them to a soil type, other considerations, along with feasibility should be considered, such as capability and suitability (Hills 1967)

Storie (1959) lists eleven possible reasons why there should be soil studies and land classification in relation to the irrigability of land. One of the reasons is to determine drainage needs of specific soil types. By using a simple characteristic map, drainage needs can be

defined for each soil type. He developed the Storie-Index rating which is used in many other reports and publications (cited later). Rating soils according to their productivity, their drainability, and their irrigability has become important in land classification techniques. Harris and Hansen (1961), in assigning productive value to land, have used such a technique. Various curves relating productivity against parameters affecting productivity are used. On a scale of one to a hundred, the soil factor is given a rating. The final rating of the soil is the product of the ratings of the factors. To test the validity of such a technique, a detailed investigation can be made for the area. Millette and Searl (1968) also used a similar technique on soils in eastern Canada.

2.3.2 Parameters used

In Europe some work has been done in relating various parameters with soil type in an attempt to classify land. Vandamme and De Leenheer (1969) report that soils in Belgium are identified using three characteristics, that is, the texture of the soil, the drainage class, and the profile development. The drainage class is based only on visual observations of assumed or presumed water-table fluctuations. For this reason, a study was initiated so that actual water-table fluctuations could be related to the drainage class selected for that soil type. As a result, recommendations were made concerning what crops could be grown on what type of soil. In The Netherlands, Van Heesen (1970) uses the

mean highest water table and the mean lowest water table for defining and obtaining a map of the water table. He then applies this map of water table classes to rating soil suitability for agriculture, horticulture, forestry and land consolidation areas.

In the United States, Beauchamp and Fasken (1955) use soil types as a basis for drainage recommendations. Combining the efforts supplied by the soil scientist, agronomist, engineer and farmer's experience, drainage recommendations were tabulated for a number of soil types throughout the United States. The drain depth and spacing along with surface drainage recommendations were also included in their guide.

For an irrigation project, other methods have been used in grouping soils. Myers et al (1962) used interpretative soil groupings for a drainage classification system. They found that such a drainage classification had the advantage of eliminating from the list of problem soils those that have obvious solutions. The interpretative soil groupings were divided into drainage groups, using the water table fluctuations as the defining criteria, which were then subdivided according to texture, permeability or hydraulic conductivity, and water holding capacity of the subsoil, of a specific soil series. A well-defined drainage classification will aid economists in searching for data and applying this data to better land use.

Fly (1961) developed a drainability classification

which is based on the hydraulic conductivity of the soil and the depth to the impermeable barrier. Curves for drainability classes were plotted and from these curves, capability classes of soil drainability factors were determined. Finally, a soil drainability rating guide was produced for evaluating lands for irrigation use.

Another drainage guide was developed by Dickey and Johnston (1973) for Fresno County in California. They based this drainage guide on a water-table drawdown at mid-point between drains 15 days after irrigation. From the data obtained, a soil permeability group map was created showing various soil types according to similar profile and permeability characteristics. To produce such a guide, existing drainage systems are needed for study and evaluation. Such maps and guides permit drainage systems to be planned and studied more efficiently.

2.3.3 Soil rating on the Canadian Prairies

In Alberta, a soil rating table was first presented to the Government of Alberta in February, 1930 (Bowser and Moss 1950). This table was based on soil productivity. For rating soils in proposed irrigation projects, the original "Table of Ratings" was modified to accommodate new principles such as heavy-textured soils versus medium-textured soils. The former would be rated lower for irrigation purposes than the latter. Bowser and Moss used seven factors in classifying and rating soils which are still in use today. In 1960, the land classification of the Bow River

Project (C.D.A. 1960) was developed as a combined physical and economic classification. A revised method for rating irrigation soils of Saskatchewan and Alberta was preseneed by Moss and Bowser (1961). The need occurred when they discovered that the soil rating should not include topography as an irrigation factor.

Dehm (1961) recognized the need for land classification for irrigation in Saskatchewan. Until recently, water was brought into an area regardless of the suitability of the soil for irrigation and drainage. In trying to maintain cost per acre within limits, new concepts were developed and an economic classification for irrigation has arisen.

A handbook for the classification of irrigated land in the Prairie Provinces was finally presented by the Prairie Farm Rehabilitation Administration (C.D.A. 1964) in 1964. The combined efforts of many people resulted in a classification that deals with the physical factors (soil, topography, climate) and the economic factors.

Chapter 3

STUDY AREAS

One of the requirements in a study such as this is gathering the pertinent data from different establishments. The areas to be studied are two drainage basins, the South Fincastle Drainage Basin (S.F.D.B.) and the MacLaine Drainage Basin (M.D.B.), in the Taber Irrigation District (T.I.D.) and the St. Mary River Irrigation District (S.M.R.I.D.), respectively. Both of these areas have had an extensive water table study through the use of observation wells located on a one-mile grid. Other data, related to the study, were also collected by various agencies. The following agencies contributed these data:

1. Alberta Department of the Environment, Earth Sciences and Licensing Division, Lethbridge, Alberta.
2. Taber Irrigation District, Taber, Alberta.
3. St. Mary River Irrigation District, Lethbridge, Alberta.
4. Alberta Soil Survey, Edmonton, Alberta.

The Alberta Department of the Environment, Earth Sciences and Licensing Division, provided observation well records from 1962 to 1973 inclusive, for the South Fincastle Drainage Basin, and from 1965 to 1973 inclusive, for the MacLaine Drainage Basin, published and unpublished reports, and various maps. The 1970 aerial photographs of both areas

were also available. The Taber Irrigation District made available their water delivery records (ditch rider records along with some annual reports). Similarly, the St. Mary River Irrigation District provided their ditch rider records. All soils information was obtained from the Alberta Soil Survey Report of the S.M.R.I.D. (Bowser et al 1963).

3.1 South Fincastle Drainage Basin - T.I.D.

3.1.1 Location

The Taber Irrigation District is located about 30 miles east of the City of Lethbridge and has as boundaries, the Oldman River on the north and the St. Mary River Irrigation District Main Canal on the south. In 1972, the Taber Irrigation District had an assessment roll of 59,833 acres, of which 52,470 were actually irrigated (T.I.D. 1972). The district is divided up according to distribution systems, which are called drainage basins. The study area is called the South Fincastle Drainage Basin, which includes parts of Township 9 and 10, Ranges 15 and 16, W4. Horsefly Lake Reservoir is at the south end with Fincastle Lake at the north end (see figure 3.1).

3.1.2 Soils and geology

General

The Taber Irrigation District is situated entirely in the semi-arid Brown Soil Zone. The study area consists mostly of glacio-lacustrine deposits and some glacio-fluvial deposits. The lacustrine sediments are composed of sand, silt, and clay of thickness generally less than ten feet.

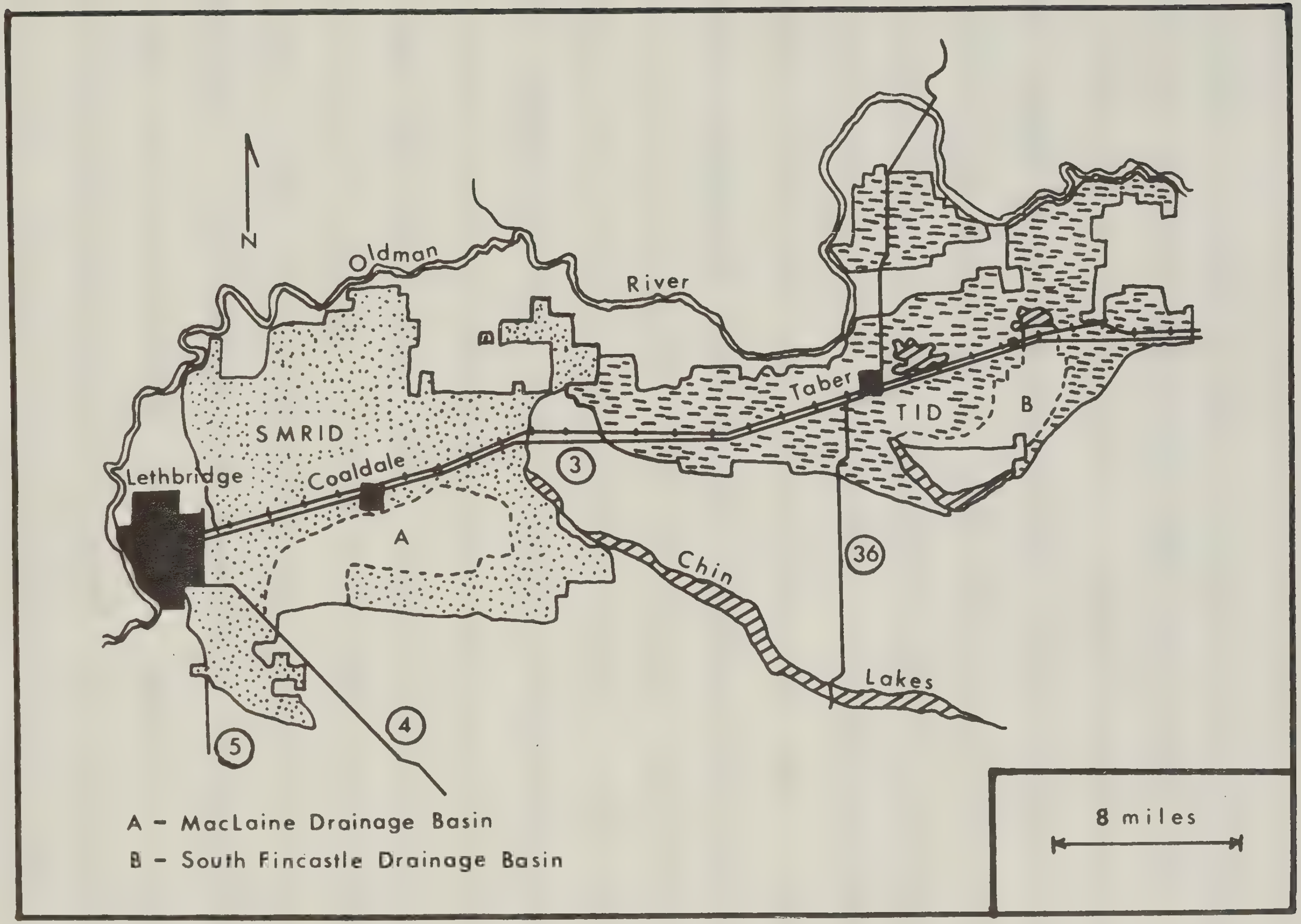

Figure 3.1. Location map.

The outwash and alluvial sediments of glacio-fluvial deposits are composed of sand, gravel and some silt. In general, underlying till texture is fairly sandy to a sandy clay loam. The bedrock is, on the average, 50 feet below the till, except north of Horsefly Lake, where it comes relatively close to the surface (Westgate 1968 and Geiger 1965).

Most of the soils in this drainage basin come under the soil order of Chernozemic soils. Only two small areas are of the Solonetzic order. The Chernozemic soils are all Orthic Brown soils, while the Solonetzic soils are Brown Solodized Solonetz. The Chernozemic soils are the Chin and Cavendish series, plus the shallow phase of each. New names have been assigned to these shallow phases: the shallow Chin loam is now called the Cranford (Cf) loam; the shallow Cavendish sandy loam is called Antonio (Ao) sandy loam; the shallow Cavendish loamy sand is now the Purple Springs(Pl) loamy sands; and the Cavendish sandy loam is called the Bingville (Bv) sandy loam. The Wardlow loam is the only Brown Solodized Solonetz in the basin. The Orthic Brown soils have a pale brown A horizon that is loose to granular in structure. The B horizon is a brown to yellowish brown, which indicates good natural drainage. Depending on the texture, the structure can be prismatic in intermediate textured soils or blocky in fine textured soils. The Brown Solodized Solonetz have a leached Ae horizon followed by a strongly columnar B horizon. Another peculiarity about these soils is the abrupt textural break between the first two

horizons. The B horizon contains a considerable quantity of exchangeable sodium.

Detailed Soil Description

The Chin loams (Ch.LtL,VFSL, L, SiL) were developed on water-sorted material, which overlies the glacial till. The till is on the average four feet from the surface. In the Cranford loams (Cf.L) the till is on the average two feet below the surface and often found at depths less than three feet. These two soil series are located mostly on level to gently undulating topography. In rating these soils for irrigation, the Chin loams are good to very good while the Cranford loams are fairly good to good.

The Bingville sandy loams and Cavendish loamy sands were developed on sandy alluvial parent material, which overlies the glacial till. The till varies in depth, averaging five feet below the surface. For the Antonio and Purple Spring series, the depth below surface is often less than three feet, but averages about two feet. All of these soils are mostly located on level to undulating (humpy) topography. The fine sandy loam and sandy loam areas are rated good to very good for irrigation, while the loamy sand areas are rated poor to fair for irrigation.

The Maleb loam was developed on glacial till parent material. The till can be found at depths of two feet. At greater depths, in the C horizon, such materials as granite, ironstone, and coal can be found. These soils are located on gently undulating to rolling topography. They are rated

as fairly good to good irrigation soils.

The Wardlow loams were developed on alluvial lacustrine parent material of medium lime carbonate content, and of appreciable salt content. The parent material overlies the till, which averages four feet in depth. They are located on gently to undulating topography, and occupy the less well-drained positions. The B horizon is nearly impermeable. These soils can be rated from poor to fair for irrigation.

Most of the area consists of Cranford loam, Chin loam, Cavendish loamy sands, Bingville sandy loam, and Purple Springs loamy sands. For more detail on these soils, refer to Bowser et al (1963) and to Appendix A. Figure 3.2 shows the enlarged portion of the South Fincastle Drainage Basin, with the soil types.

3.1.3 Climate

The Taber region is one of the better suited areas for growing corn in all of the irrigation districts of Alberta (Hobbs 1970). The higher mean growing season temperature (May to September) of nearly 60°F. provides adequate energy for growing corn and other similar crops. There has been, on infrequent occasions, summer highs of above 100°F. and winter lows as cold as -40°F. The average number of days during the growing season free of killing frost (not below 28°F.) is 148 days, ranging from 152 in the east, to 146 in the west of the irrigation district.

The precipitation, for the interval of May to Sep-

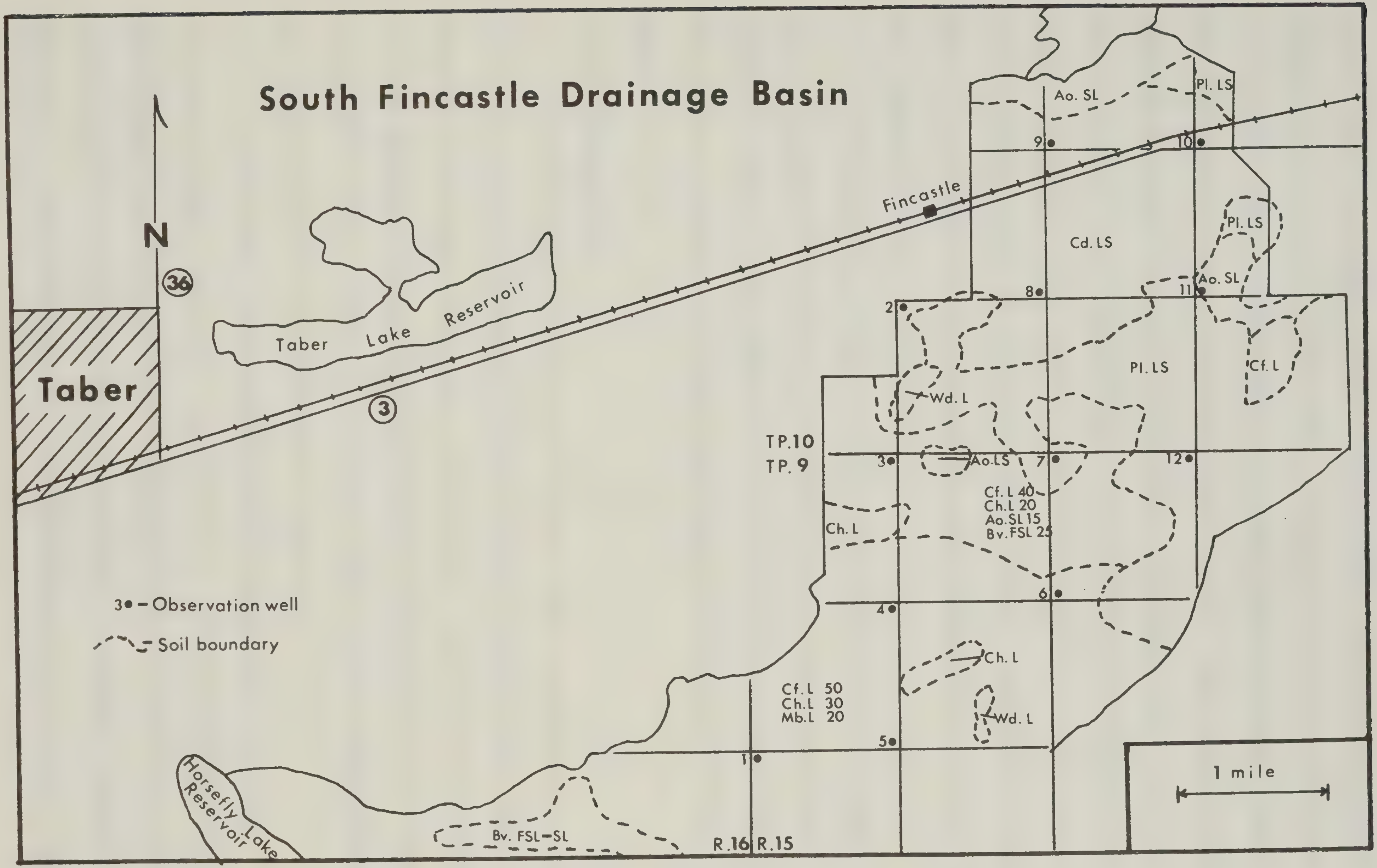

Figure 3.2. Soils map and well locations of S.F.D.B.

tember, has averaged about nine inches. For the period of water table records (1962-1972 inclusive) the monthly precipitation, the monthly mean maximum and the monthly mean minimum temperature have been tabulated. (See Appendix B.) Seventy-five per cent of the annual precipitation occurs between April 1st and October 31st, with the month of June averaging about 2.5 inches. According to Dr. A.H. Laycock, of the University of Alberta, there is an average deficit of about ten inches in the area between Lethbridge and Medicine Hat (Bowser et al 1963).

Prevailing winds are from the west in the summer, with a total of 80,000 to 90,000 miles of wind per year (Hobbs 1970). Only one per cent of the days are calm. For the growing season the wind may range around 5,000 miles per month.

3.1.4 Irrigation

The Taber Irrigation District was organized in 1915, with an original area of 17,000 acres. Since then, the District area has increased threefold. In 1972, 88 per cent of the assessed acres were actually irrigated (T.I.D. 1972). As of 1969, in the T.I.D., 70 per cent of the acres irrigated were irrigated by sprinkler systems.

The water table measurements were made from 14 shallow 15-foot wells in the S.F.D.B. These perforated 3-inch pipes are located on a one-mile grid. The water table readings are taken at about a two-month interval throughout the year. The accuracy of the measurements is within one-

hundredth of a foot. A map showing their location in relation to the soil types in that area is provided in figure 3.2.

The Alberta Department of the Environment (1970) has published maps with the irrigation water distribution system and irrigable land classification for the South Fincastle Drainage Basin. These will be used in a later chapter.

3.1.5 Drainage and drainage problems

The South Fincastle Drainage Basin was chosen as an area having a potential drainage problem. In an unpublished report (Van Orman and Rapp 1949), the authors state that there had been no artificial drainage done in this area. The South Fincastle Drainage Basin lacks any deep drains, and seems to have a rising water table as a result (McCracken 1973). The water table data for the 11-year period of 1962-1973 inclusive, is given in Appendix C. For each well location, there were soil borings, which recorded soil texture for one-foot intervals and depth to till.

3.2 MacLaine Drainage Basin - S.M.R.I.D.

3.2.1 Location

The study area is located in the St. Mary River Irrigation District, Western Division. The Western Division is situated just west of the City of Lethbridge and extends east to Chin. The MacLaine Drainage Basin is situated in parts of Townships 8 and 9, Ranges 19, 20 & 21, W4. All of the study area is south of Highway No. 3, and is bounded in part by the S.M.R.I.D. Main Canal. Figure 3.1 shows the location of the MacLaine Drainage Basin.

3.2.2 Soils and geology

General

The MacLaine Drainage Basin is situated entirely in the Dark Brown Soil Zone. Most of the surface deposits are glacial. The deep soils, as opposed to the shallow phase, are lake deposits composed of silt, sand and minor clays. The shallow profiles are on hummocky and ground moraine composed of till of variable depths (2 to 10 feet). A small area in the north-west corner of Township 8 and Range 20,W4, was formed from aeolian deposits composed of sand and silt. The Upper Till is composed of bouldery sand and gravel at the top and bottom (Nielsen 1971b). The bedrock, mostly Oldman formation, lies well deeper than 100 feet in some areas (Geiger 1965).

Most of the soils in the MacLaine Drainage Basin come under the soil order of Chernozemic soils. In the centre of Section 16, Township 9, and Range 19, there is an area of Gleysolic soil. The Chernozems are all Orthic Dark Brown, while the Gleysolic soil is an Orthic Gleysol. The soils mapped as Chernozems are the Lethbridge, Whitney, Coaldale, Shallow Coaldale and Readymade series. These Dark Brown Chernozems were developed in a semi-arid climate, which is slightly more humid than in the areas of Orthic Brown Chermozems. The change between the two is very gradual and an arbitrary north-south boundary goes through Chin. The A horizon is dark brown in colour, but the C horizon is much lighter in colour, where there is a lime carbonate accumula-

tion. The B horizon has a prism-like structure.

Detailed Soil Description

The Lethbridge loams (Leth. SiL , L) were formed on alluvial lacustrine parent material of fairly high lime carbonate content. The counterpart of the Lethbridge loams are the Chin loams. The glacial till varies in depth, but on the average is found to be at five feet. The shallow Lethbridge series is now called the Whitney series (Wy). Both of these soils are mostly located on gently sloping to very gently sloping topography. The Lethbridge loams are rated as very good irrigation soils. The Whitney loams are rated lower, due to the depth of till, which is, on the average, less than three feet.

The Coaldale silty clay loams (Cdle. SiCl) were developed on fine textured lacustrine parent material of varying depths. Clay deposits of 10 feet in thickness are not uncommon. Beneath this clay, the glacial till is encountered. Both the Coaldale and shallow Coaldale silty clay loams are located on level to gently sloping topography. In depressional areas accumulation of salt can become a problem. The Coaldale silty clay loam is considered as a good irrigation soil if certain managerial steps are followed, as described by Bowser et al (1963). For further information and more detail see Appendix A and Bowser et al (1963). Figure 3.3 shows the drainage basin with the soil types.

3.2.3 Climate

The immediate Lethbridge area is a borderline area for

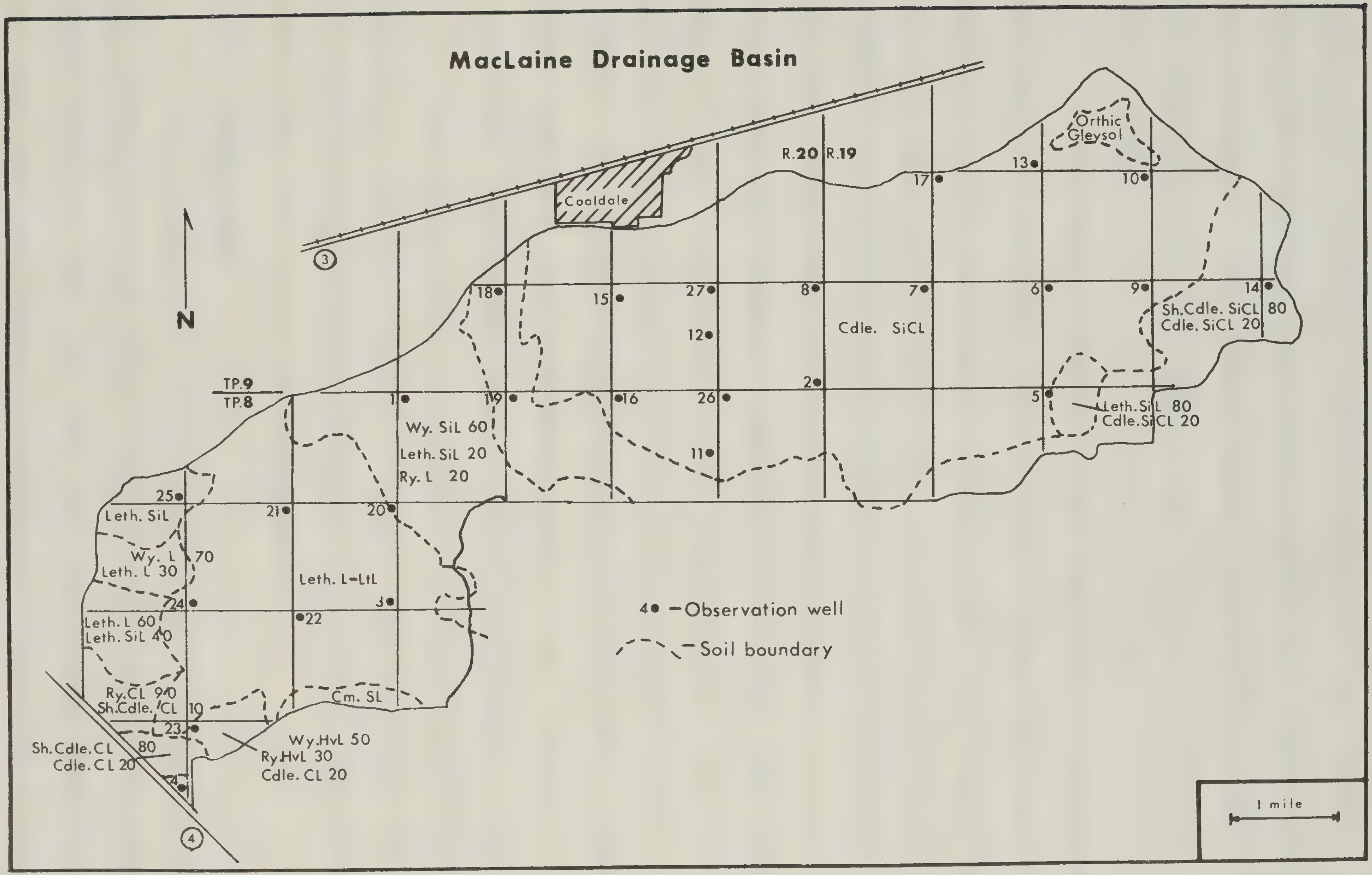

Figure 3.3. Soils map and well locations of M.D.B.

maturing the presently available grain corns. Other crops requiring less heat are more desirable in this region. Temperature extremes such as over 100°F. and -45°F. have been recorded. The growing season (killing frost 28°F.) has averaged 139 days ranging from 110 days to 178 days (Hobbs 1970).

The seasonal precipitation (from May to September) has averaged more than 9 inches with a yearly average of 16-18 inches for the period of 1902-1969. For the period of water table data (1965-1972), the monthly precipitation, monthly mean maximum temperatures and the monthly mean minimum temperatures were tabulated by the Agriculture Canada Research Station, Lethbridge, Alberta. (See Appendix B.) Most of the rain occurs between April 1st and October 31st, with the month of June averaging just over three inches. The average evaporation from a four-foot diameter sunken pan over the five-month (May to Sept.) season is 24.3 inches for the 46-year period of 1923-1968 (Hobbs 1970).

The chinook area of Alberta is characterized by winds averaging about 13.4 miles per hour. The direction of prevailing winds is west throughout the year. The calmest months are July, August and September.

3.2.4 Irrigation

The Lethbridge-Coaldale area, which started under the Alberta Railway and Irrigation Company, had an irrigation canal built by 1902. In 1946, the area became known as the St. Mary and Milk Rivers Development. Since then, the pro-

ject area has been divided into numerous other projects. In 1972, the Lethbridge-Coaldale area of the S.M.R.I.D. had over 87,000 acres of irrigable land of which 63,248 acres were actually irrigated (S.M.R.I.D. 1972). The major crops grown in the area are grain crops, hay, and sugar beets.

Since 1965, there have been 27 shallow 15-foot water table wells installed in the MacLaine Drainage Basin. Many of these were installed for the International Hydrologic Decade (I.H.D.) project undertaken from 1967 to 1971. These wells are read at least six times per year. The irrigation water distribution map of the drainage basin was obtained from the Alberta Department of the Environment. The S.M.R.I.D. Office in Lethbridge provided additional information such as annual reports and some water delivery records for the MacLaine Drainage Basin. The two main types of irrigation systems used are sprinkler and gravity systems.

3.2.5 Drainage and drainage problems

The general slope of the West Division is to the north-east with the north section draining into the Oldman River via Six Mile Coulee, Northeast Reservoir Spill and Bountiful Coulee (Nielsen 1968). The main drains constructed in the area are the Six Mile Coulee Drain, the Malloy Drain and the Coaldale Drain. Some surface drainage is provided along Highway No. 3 from Lethbridge to Chin. The surface drainage network is set up so that the unused water re-enters the S.M.R.I.D. distribution system. The Malloy Drain originates in the MacLaine Drainage Basin and

terminates in the Chin Lakes.

Nielsen (1971a) states that most of the West Division is a recharge area, i.e. groundwater percolates down from the land surface. Groundwater discharge is not a problem. Discharge areas are easily identified, such as, salt deposits, phreatophytes, barren ground, sloughs, etc; however, in an irrigated area, caution should be exercised in interpreting such phenomena. From the I.H.D. Basin Study, the groundwater outflow was found to have the same magnitude as the inflow from deep percolation, seepage from dugouts and ditches, and over-irrigation (Nielsen 1970). If these parameters are equal, then there should be no buildup of groundwater.

For the period of 1964 to 1973, the water table data is presented in Appendix C. Other information that was available with the previously mentioned data is the soil borings at each well location. The soil texture for each interval of one foot is given along with the depth of till.

Chapter 4

METHODS AND PROCEDURES

Four techniques were used for conducting a reconnaissance drainability classification of soils in an irrigated area. The first two methods are interpretative ways, while the last two are empirical approaches. These are further described in the following sections.

4.1 Aerial Photographs

Black-and-white aerial photographs provide considerable information. Some drainage problem areas can be identified through the use of such photographs.

Wet areas or areas of phreatophytic vegetation clearly indicate an area which has "free" water at or near the surface of the ground. If the area occurs within a solonetzic soil, the problem could be even more serious. Areas where sodium salts appear at the surface can also be identified. These are commonly called "slick spots". They provide a drainage danger signal, but the problem solution is not always obvious.

In interpreting aerial photographs, vegetative cover recognition is sometimes difficult. Therefore, the limitations of aerial photograph interpretation should be clearly indicated. An aerial photograph does not replace an actual field investigation, but can certainly guide the engineer in determining how extensive an investigation should be. The ultimate advantage of aerial photographs is

the rapid identification of problem areas.

In 1971, the Alberta Department of the Environment, Water Resources Division, used the 1970 aerial photographs of the Taber Irrigation District for their aerial photograph interpretation. The ponded, seepage and saline areas were then superimposed on a mosaic prepared from the aerial photographs taken in 1962. To verify the areas that were interpreted from the photographs, an actual field check was conducted by the author. A similar aerial photograph interpretation was done by the author on the MacLaine Drainage Basin in the S.M.R.I.D., West Division, along with a field check.

4.2 Soil Survey Drainage Classification

The descriptions of the soil profiles were obtained from the Soil Survey of the St. Mary and Milk Rivers Irrigation Development (Bowser et al 1963). The soil drainage class for each soil type was not provided in this report. By using the soil drainage classes described by the System of Soil Classification in Canada (C.D.A. 1970), and the soil survey report, the soil types of the two areas were assigned a drainage class. If the till in the shallow soil series possesses a lower hydraulic conductivity than that of the overlying material, the soil was given a lower drain age class for the subsoil. Most of the shallow profiled soils in these two areas have two drainage classes, one for the surface soil and the other due to the subsoil. The remaining soils were assigned one drainage class, since the

depth to till was assumed to be sufficiently deep. Some soils possessed similar drainage classes and therefore were combined to compose a larger unit.

4.3 An Empirical Drainage Classification

By approaching the method that previous authors have used (Bowser and Moss 1950; C.D.A. 1960; C.D.A. 1964; Fly 1961; Millette 1969; Mitchell 1939; Myers et al 1962; Storie 1957), for the classification of soils for irrigation, for agriculture, or for drainage, a similar technique was developed for the drainage classification of some soils in southern Alberta.

4.3.1 Defining the factors

From the investigations conducted by Donnan and Bradshaw (1952), the important soil characteristics to be considered when designing a drainage system were determined. The points to be considered were: (1) kinds of soils, (2) thickness of the various strata, (3) continuity of strata, and (4) position of the various strata with respect to the ground surface. Fly (1961) uses some of these characteristics in his soil drainability rating guide.

The "soil" was divided into two sections: the surface and the subsurface. The surface section is the soil profile from the ground surface down to the bottom of the IIC horizon . This could be shallow in some cases and deep in others. The subsurface section starts at the bottom of the C horizon. From the descriptions of the soils given in the soil survey report (Bowser et al 1963), a table can be

produced showing the soil type, average texture of surface section, topography, average depth to till or to impeding horizon, and the hydraulic conductivity of the subsoil. All of these descriptions are qualitative and use the correct terminology as provided by the System of Soil Classification for Canada (C.D.A. 1970).

For the surface section, only the average texture of the profile and surface topography were considered to be important in a drainage rating. Similarly for the subsurface, only the depth to the glacial till or to the impeding horizon, and the hydraulic conductivity of the subsoil were used in the drainage classification. Myers et al (1962), in the drainage divisions, use the water-holding capacity in the definition which is usually related to texture. For the purpose of this study, the average texture of the surface section was selected as one of the factors. Rough topography in some cases, as described by the soil survey report (Bowser et al 1963), results in poorly drained spots. Therefore, topography should be considered as one of the factors. Fly (1961) makes use of the depth to barrier, stratification and hydraulic conductivity. Using the depth to the glacial till or the depth to the impeding horizon (whichever is more critical) seems to be the comparable factor to use in this study, along with the hydraulic conductivity of the subsoil.

4.3.2 Rating the soil factors

Having decided which soil factors affect drainage,

each of these factors must be subdivided in order that they can be rated. The soil texture was subdivided into three major groups: Heavy, medium and light. Some authors subdivide texture in this way because of simplicity (C.D.A. 1964; Nielsen 1968). Using the Handbook for the Classification of Irrigated Land in the Prairie Provinces, each subdivision includes the soil textures shown in table 4.1.

Table 4.1
Texture subdivisions and ratings.

Textural class	Texture	Rating
Heavy	SC, SiC, SCL, CL SiCL, C, HvC, VHvC	20 - 30
Medium	FSL, VFSL, L, SiL	31 - 40
Light	CS, VFS, LCS, LVFS, SL	41 - 50

The heavy textured soils will be rated lowest, with the light textured soils being rated the best for drainage. The soil texture was assigned a maximum rating of 50. Using this and applying this rating to the textural class, the texture rating was established as shown in table 4.1.

The topography classification was the same as the one established for land leveling in the Land Classification of the Bow River Project (C.D.A. 1960). Table 4.2 provides the description of each topographical class along with the ratings. Again, the maximum rating assigned was 50.

Table 4.2
Topography subdivisions and ratings.

Topographical Class	Description	Rating
T_1	Includes very gently sloping, VGS Gently sloping, GS Very gently undulating, VGU	41 - 50
T_2	Gently undulating, GU	31 - 40
T_3	Rougher phase of gently undulating, RGU Gently undulating to undulating, GU-U	15 - 30

By summing the texture rating and the topography rating, a surface rating can now be calculated:

$$SR = TxR + ToR$$

where

SR = surface rating expressed as a percentage

TxR = texture rating

ToR = topography rating

For the subsurface rating, similar techniques were used for the depth to glacial till and hydraulic conductivity. The depth to glacial till was subdivided into two groups, shallow and deep. The reason for this is that firstly the information from the soil survey report (Bowser et al 1963) was not sufficiently accurate and secondly, most of the soils are distinguished by their profile depth, for example, Chin loam and Cranford loam. Another situation, which could be limiting before the depth to till, is a

nearly impermeable horizon occurring above the till. This is the case in some Solonetzic soils, which have a heavy textured Bnt horizon. In this case, the rating is obtained by using the same rating as for the shallow depth of till. The maximum rating assigned to the depth to till was 50. Table 4.3 shows the ratings. Fly's (1961) ratings of the depth to barrier are comparable to those below.

Table 4.3
Depth to glacial till subdivision and ratings

Depth of till	Description	Ratings
Shallow	average depth of less than 4 ft.	15 - 30
Deep	average depth of 4 ft. or more	31 - 50

The hydraulic conductivity class for the subsoil was similar to that already established (C.D.A. 1964). Again, only two classes were used due to insufficient and inaccurate data. From the description of the soils some indication of the hydraulic conductivity was given in qualitative terms. Therefore, by using the hydraulic conductivity values for the C horizon provided by the soil survey report, an estimate can be obtained and a rating applied. Table 4.4 provides this information.

Table 4.4
Hydraulic conductivity subdivisions and ratings.

Hydraulic conductivity	Description	Rating
Moderate - moderately slow	.1 - .3 ins/hr.	31 - 50
Slow - to very slow	less than .1 ins/hr.	less than 31

By summing the depth-of-till rating and the hydraulic conductivity rating, a subsurface rating can now be calculated:

$$SbR = DR + HCR$$

where

SbR = subsurface rating expressed as a percentage

DR = depth of till rating

HCR = hydraulic conductivity rating

By multiplying the surface rating by the subsurface rating a final drainage rating is now obtained:

$$FSDR = SR \times SbR$$

where

FSDR = final soil drainage rating as a percentage.

4.3.3 Soil drainage classes

The most important step in using this empirical drainage classification is determining the group or class; whether the soil is rapidly, well, moderately well, imperfectly, poorly or very poorly drained. The group selection in which the soil drainage rating should be is more important

than the rating itself. That is, whether a soil should be classed as rapidly drained or well drained is more significant than a difference of 5 points in the individual ratings, say 40 and 45.

There is no set procedure in determining the range of each group. However, by using the soil drainage rating for the soil type which is described as being the best drained in the area, a first group is set so that it includes that soil rating. According to Bowser and Moss (1950), the first group should have the widest range, the second one a narrower range, and so on. The highest rating of 68 belongs to the Cavendish loamy sand series on level to very gently undulating topography. From the soil description, this series is classed as a rapidly drained soil. The first group will include 68. The Chin loam is rated at 56 and from the soil description is classed as well-drained. This would indicate that Chin loam belongs to the next group. Now, the range of the first group is set at 100 to 65. The second group will have a narrower range. The range should include the Maleb loam since from the soil description, the Maleb loam is classed as well to moderately well-drained. Now, the range of the second group is set at 64 to 38. For the third group the range should include the shallow Coaldale silty clay loam rating of 21, since it has the lowest rating of the moderately well-drained soils. The range of the third group will be from 37 to 20, in order to include all moderately well-drained soils. The final group will include the imperfectly, poorly

and very poorly drained soils. These groups are summarized in table 4.5. These ranges within each group were determined after the empirical drainage classification was completed. (See tables 5.2 and 5.6.)

Table 4.5
Empirical drainage classes and corresponding range of rating.

Drainage group	Drainage class	Rating range within group
1	Rapidly drained (R)	100 - 65
2	Well-drained (W)	64 - 38
3	Moderately well-drained (MW)	37 - 20
4	Imperfectly, poorly, very poorly drained (I, P, VP)	below 20

These particular ranges for each class apply only for the soils studied in this area. In another area a similar procedure would have to be applied and modified.

4.4 Water Table Classification

The water table has been defined (Hiler 1969) and classified (Myers et al 1962; Vandamme and De Leenheer 1969; Van Heesen 1970;) in many ways. Before the water table information can be properly used, the data must be summarized in a way that is the most descriptive. Once summarized, the water table data is then classified and wells can be compared. This section will develop the tech-

nique, thus obtaining the fourth and final drainage classification for the two areas.

4.4.1 Statistical technique used

The observation well readings were taken at approximately two-month intervals for the two areas. Choosing one well along with the continuous period of record of this well, an autocorrelation was done (Chow 1964; Rigs 1969; Yevjevich 1972). By plotting the autocorrelation coefficient against the lag period, the resulting correlogram is examined. For most of the wells a one-year cycle was noticed. (See Appendix D.) Summarizing the data then became an obvious procedure, which is described below. Bi-monthly water-table readings can be represented as:

$$X_1 = x_1, x_2, x_3, \ldots x_7 \ldots x_n$$

where

X_1 = discrete series of readings for Well No. 1

x_1 = January reading for 1st year

x_2 = March reading for 1st year

x_3 = May reading for 1st year

x_7 = January reading for 2nd year

x_n = final reading for that well for the last year.

If plotted against time, the foregoing series results in the hydrograph for Well No. 1. All the wells follow the same pattern. The one-year cycle was noticed from the correlogram where the autocorrelation coefficient peaked at an equal lag period of six readings. Six readings correspond to a 12-month period or one year. Since every well read-

ing seemed to be repeating in a cycle of six readings, an average for the two-month period was calculated. The following equation describes this:

$$\bar{X}_{J1} = \frac{x_1 + x_7 + x_{13} + x_{19} \cdots}{N_{J1}}$$

$$\bar{X}_{Mr1} = \frac{x_2 + x_8 + x_{14} + x_{20} \cdots}{N_{Mr1}}$$

$$\bar{X}_{N1} = \frac{x_6 + x_{12} + x_{18} + x_{24} \cdots}{N_{N1}}$$

where

$\bar{X}_{J1}$ = mean of January readings for the length of record, for Well No. 1.

x_1 = 1st January reading for Well No. 1

x_7 = 2nd " " " " "

x_{13} = 3rd " " " " "

and so on.

$\bar{X}_{Mr1}$ = mean of March readings for length of record, for Well No. 1.

x_2 = 1st March reading for Well No. 1

x_8 = 2nd " " " " "

x_{14} = 3rd " " " " "

and so on.

$\bar{X}_{N1}$ = mean of November readings for length of record, for Well No. 1.

x_6 = 1st November reading for Well No. 1

x_{12} = 2nd " " " " "

x_{18} = 3rd " " " " "

and so on.

N_{J1} = No. of January readings for Well No. 1

N_{Mr1} = No. of March readings for Well No. 1

N_{N1} = No. of November readings for Well No. 1

and so on.

This equation can be used for all the wells. The wells that are missing either had a discontinuous period of record or the readings were too unreliable. The mean and the standard deviation were both calculated for each two-month period for most of the wells.

This way of summarizing the data shows the monthly periods which tend to have a high water table or low water table. The seasonal effects are obvious and very useful in describing the water table.

4.4.2 Defining the water table factors

Myers et al (1962) defines drainage groups according to water table fluctuation, minimum depth during most of the year, and the period of time this water table occurred or persisted. In the Handbook (C.D.A. 1964), there are also various groundwater conditions specified for rating drainability of soils. Using these factors as guides, three water table factors were thought to be the most important: (1) the degree of fluctuation or the difference between the maximum and minimum water table reading for a well, (2) the shallowest water table depth during the growing season, (3) the time period at which this water table occurs. A modification factor has to be included in order to compensate for the number

of readings taken during a 12-month period. None of the three previously mentioned factors take into consideration the number of water table readings that occur between certain defined ranges. This will be explained in the next subsection.

A fluctuating water table (rather than a steady-state condition) provides the best available characterization of the physical situation in the field (Hiler 1969). Good crops could be produced under a high water table condition, but a fluctuating water table is a more serious problem.

The shallowest water table reading also reflects the severity of the drainage problem. Some authors use five-feet or deeper as the limiting depth (Fly 1961), or 54 inches for the best condition (Myers et al 1962). The Handbook (C.D.A. 1964) suggests that a water table of deeper than 8 feet for most of the year is a satisfactorily drained soil, but 5 feet seems to be the limiting depth. Considering these depths, a classification was established which is explained in the next section.

The time at which the minimum water table occurs is also important, especially when this condition occurs during the growing season. When plants establish their full root zone early in the summer, the ideal condition for them is a rapidly receding water table. This water table recession will tend to develop a deep root zone. If the high water table period occurs later in the summer, flooding of the root zone is inevitable and so is root damage. Another water

table condition exists after the snow melts in the spring (March and April) when the water table usually rises. During May the water table has receded and stabilized. If a high water table still persists in May, a delay in seeding can result, followed by a possible drainage problem.

4.4.3 Rating the water table factors

Having decided which water table factors are the most critical, each of these must be subdivided in order that they can be rated. The degree of fluctuation and shallowest depth factors were each given four subclasses of equal increment. The time factor was divided into three classes.

To eliminate making a decision on subclass division, equal increments were set for the degree of fluctuation. Table 4.6 presents these and also indicates the possible range for rating each subclass.

Table 4.6
Water table fluctuation subdivisions and ratings.

Class	Degree of annual fluctuation in feet	Rating %
1	0 to 2	80 - 100
2	2.1 to 4	60 - 79
3	4.1 to 6	40 - 59
4	greater than 6.1	less than 40

By using the summarized data as previously described, the degree of fluctuation was calculated for each well. The ratings were then determined from those ranges.

For similar reasons described previously, equal increments were set for the shallowest depth occurring during the growing season. Table 4.7 shows these subclasses along with their corresponding range of ratings.

Table 4.7
Shallowest water table depth subdivisions and ratings.

Class	Shallowest depth during growing season, in feet	Rating %
1	greater than 6	80 - 100
2	4.1 - 6	60 - 79
3	2.1 - 4	40 - 59
4	less than or equal to 2.0	less than 40

The year was divided into three distinct periods: (1) the winter months or months where no crops are grown, November to April, (2) the month of May, (3) the months of July and September. The readings were available only on a two-month basis and therefore the only months that could be used were January, March, May, July, September and November. Table 4.8 shows this along with the corresponding range of ratings.

Table 4.8
Time intervals and ratings.

Class	Time interval	Rating %
1	November, January, March	80 - 100
2	May	75
3	July and September	40 - 74

So far, only the range of water table depths, the shallowest water table depth and the time at which this shallow water table occurs have been used to characterize the water table for one well. The other water table readings were not considered and therefore a modification factor was included. This modification factor uses the same range of depths as does the shallow depth characteristic. Table 4.9 illustrates the ranges, along with the acceptable number of readings within each range, their weight and the formula used to calculate the rating.

Table 4.9
Modification factor ratings.

Water table depth in feet	No. of readings acceptable	Weight per reading	Formula for all ranges
0 - 2	0	15	
2.1 - 4	0	10	$100-(15N_1+$
4.1 - 6	3	5	$10N_2+ 5N_3)$
greater than 6	no limit	0	

where N_1, N_2, and N_3 are the number of readings in each class (greater than the acceptable level). For the number of readings acceptable within each range there should be no readings between 0 and 4.0 feet, but three readings between 4.1 and 6 feet is considered to be acceptable. The weighting values for each class were set so that the largest value (15) multiplied by a maximum of six (since there can only be a maximum of 6 readings) will not exceed 100. The smallest weighting value is 0 for the water table depth range of greater than six feet. Using a linear decreasing scale, the two intermediate values of 10 and 5 can be calculated.

The formula used for calculating the modification factor rating must include all of the ranges necessary. A maximum rating of 100 is obtained if all readings are greater than six feet. If the readings are within the other ranges, the appropriate reduction from 100 is calculated. The rating can never be negative. The smallest rating that could exist is 10, calculated from: 100-(6x15+0+0).

The final rating of the water table for a well is calculated by the following:

$$WTR = DF \times SD \times TP \times MF$$

where WTR = water table rating as a percentage

DF = degree of fluctuation rating

SD = shallow depth rating

TP = time rating

MF = modification factor rating

4.4.4 Water table classes

Five classes were used to group the water table ratings: very good, good, fair, poor and very poor. Defining each class with a range of numbers created a problem. By using the data, the ratings obtained for each well and sound judgment, the class ranges were produced. The reliability and usefulness of this water table classification will be further discussed in the following chapter. Table 4.10 summarizes the classes.

Table 4.10
Water table classes and
corresponding range of rating .

Class	Range of percentage
very good (VG)	65 - 100
good (G)	40 - 64
fair (F)	25 - 39
poor (P)	15 - 24
very poor (VP)	less than 15

Chapter 5

RESULTS AND DISCUSSION

When studying drainage problems in any area, definite methods should be developed. In turn, these methods must be evaluated, applied and compared, before conclusions concerning the study areas can be made. The following sections will attempt to do this.

5.1 Evaluating the Methods

The methods that were previously described have been used in various investigations which have been cited. All of these studies used one method and therefore no comparison of methods could be made. There is an advantage of having several methods in that the area can be examined from different points of view. But there is also a definite disadvantage in that the importance of each method must also be rated. Conversely, the method which best described the drainage problem should be used. The end product will be a combination of conclusions obtained by each method.

5.1.1 Aerial photograph interpretation

As stated in section 4.1, air photo interpretation is a useful technique, which can be used in irrigation districts. Unless accompanied by a field check, the air photo interpretation is not too reliable. However, if a field check is done, the information obtained is quite valuable.

A problem that often occurs when using aerial photographs, is their availability. To accomplish an accurate and

up-to-date analysis, recent and full coverage of the area is necessary, especially in irrigated areas where surface conditions can change from year to year. This last statement also indicates that aerial photo-interpretation should be done quite often in these areas in order to have sufficiently reliable information.

Another problem with aerial photographs is that they are taken mainly in the spring of the year. The conditions existing at that time might not be indicative of the conditions in the area. If average conditions are sought, the spring aerial photographs will certainly provide information for the coming summer.

Aerial photographs can assist engineers in analysing drainage problems. The main advantages are that they provide (1) a rapid overall view of the area, (2) a certain degree of reliability and confidence in detecting drainage problems since the problems exist, and (3) a map showing the present and obvious problems that are actually there. From this information, a concentration of such areas could mean a local problem, and a wide distribution of such areas could mean a regional problem.

If this information is utilized without considering any other factor, the value of the information is quite limited. In conjunction with other factors such as soil types, aerial photographs can be extremely useful as will be shown in section 5.2.

5.1.2 Soil drainage classification

Since the drainage classification of each soil type was not indicated in the soil survey report of the S.M.R.I.D., these had to be established from the description and from the System of Soil Classification of Canada (C.D.A. 1970). This is a general type of classification. Each soil type is given a description from which a drainage class is selected. The present use of the soil is not being considered, nor is the changing condition of the soil being considered. Even though the soil type is rated 'well-drained', this does not necessarily imply that all of these areas do not have a drainage problem. Managerial problems accompanied by local conditions create drainage problems. The main use of the soil drainage classification is to obtain a general drainage map of the area disregarding any local effects.

In an earlier section, these soil drainage classifications were used with the empirical drainage classification in the selection of the drainage classes. The soil drainage map provides a guide for other methods to be used. If used without considering other factors, this technique has very little value, but when compared with other techniques, this soil drainage map provides some basic information.

5.1.3 Empirical drainage classification

As previously mentioned, this method of land capability classification is widely used. In some cases the approach used is quite universal and can be applied in almost any area (Fly 1961; Storie 1957), but in instances where certain

peculiarities are present, the application of the method is restricted to that local area.

Of the four factors affecting the soil drainage, the depth to the glacial till factor seems to be a regional one. All areas having a similar type of geologic formation,such as an impermeable barrier at a fairly shallow depth, could use such an approach.

One of the greatest problems in using an empirical drainage classification is in making decisions. All factors affecting drainage should not be used since some are highly correlated. Therefore, according to the area, the farming practices and the soils, only four independent drainage factors were considered to be important. From the information available for the area, certain factors could not be included, such as hydraulic conductivity of the surface soil. Instead, factors for which information was available were developed and rated. A judgment implication is evident both in the choice of the drainage factor and in the rating of that drainage factor. Certain judgment factors are also made by soil scientists in distinguishing between soil types.

The value of such an approach is worth only as much as the information from which the ratings were obtained. The soil survey data being general can only imply that this type of an approach is also general. The specific point about this technique is that only the drainage characteristics are considered.

Two factors which were neglected in this method are

the irrigation practices and the climatic effects. Under certain irrigation systems some soils could perform better due to better efficiency, thus improving the drainage condition. Since this managerial problem is very local, and highly variable, using such a factor would be impractical in this study. Variable spring conditions can bring about rapid snow melting and result in a possible drainage problem. These conditions were not considered in this classification.

Although there are some decisions and judgments to be made when using this method, the mathematical relationships seem to combine the effects of the drainage factors and produce a drainage rating. A valuable advantage of this method is that no field data is necessary to compute the drainage ratings. The empirical drainage classification is used in conjunction with the soil drainage classification to establish the drainage classes. This means that both the soil drainage classes and the empirical drainage classification will be very similar. If more precise data were available, small areas could be evaluated using this method. However, no method can be separated from any other without significantly losing some comparative value. The empirical drainage classification method is dependent only on the soil survey report.

5.1.4 Water table classification

If the effect of adverse water table conditions is assumed to be caused by a drainage problem, then using a water table classification is acceptable. In an irrigated

area, water table conditions are of extreme importance and therefore are often monitored. For this information to be valuable, the readings should be taken throughout the year. In the case of this study, the readings were taken at two-month intervals throughout the year. Long periods of record would also be an asset since they could provide more accurate prediction data. For this study, periods of record from 5 to 11 years were available.

The long-term averages that were used to describe each bi-monthly period for the wells are an indication of the existing water table conditions. These averages then serve as a guide in rating each well. The final rating is based on these average values and apply only for the period of time covered. Since the water table is a time-variant factor, this type of classification should be repeated often. For comparison possibilities these ratings could be done on a five-year basis and verifying the previous five years with the following five years. The length of record was not sufficiently long to attempt this and therfore only one classification was possible in this study.

The areas represented by the wells are assumed to be of equal value. Each well represents an area of one square mile. In reality this might not be the case, but there was no alternative than to accept this. Davis and Matlock (1973) report that for a general type of study, as conducted here, a node spacing of 4 miles for the wells provided sufficiently accurate data. Since the wells in the basin were on a one-

square-mile grid, the wells do represent a sufficiently accurate groundwater position. Each well is a self-contained unit which describes, for an estimated area, the water table conditions. When the wells are compared, so are the areas they represent.

The first three factors used for the water table classification (degree of fluctuation, shallowest depth during the growing season, and the time at which shallowest depth occurs) described the water table from a maximum and minimum point of view. The other four readings between the maximum and minimum were not being considered. The modification factor that was developed uses these 'in-between' readings to further and more correctly rate the water table.

The soil types, the crops, the irrigation system used and the climate were not considered in this classification. The wells were not situated on all the soil types, therefore their relationship could not be determined. Furthermore, the climate, more specifically, the precipitation does influence the water table fluctuation (Rapp and van Schaik 1971), but all the wells here were under the same climatic conditions. Since the comparison of wells is within this area, there was no need to consider precipitation. The crops and the irrigation system used are highly variable from year to year, therefore making these factors difficult and impractical to use. The length of record of some wells was shorter than others. This affects the averages and the

averages affect the ratings. For this analysis this was ignored.

5.2 Application of Methods to Actual Areas

Two study areas were selected to test the validity and the usefulness of these methods. For each area, all methods cited were applied, so that a final drainage rating can be presented.

5.2.1 South Fincastle drainage basin

Aerial photograph interpretation

A map showing the ponded,seepage and saline areas is presented in figure 5.1. The term 'wet area' will be used in lieu of wet, seepage and saline areas. The concentration of wet areas is mainly situated in the north-west side of the drainage basin. The contour lines indicate a slight north-west slope on the west half of the drainage basin. Following these two observations, a relationship between the ground surface topography (10 feet contours) and the concentration of wet areas seems to be present. Another observation made from a comparison of the wet areas with the water-distribution system reveals that most of the wet areas occur along the canals. The underground water movement in this area is probably in the same direction as the slope of the surface topography.

In the northern part of the drainage basin, which consists mainly of Cavendish loamy sand soil, there occur a considerable number of wet areas. The light textured profile combined with the lower elevation could contribute to

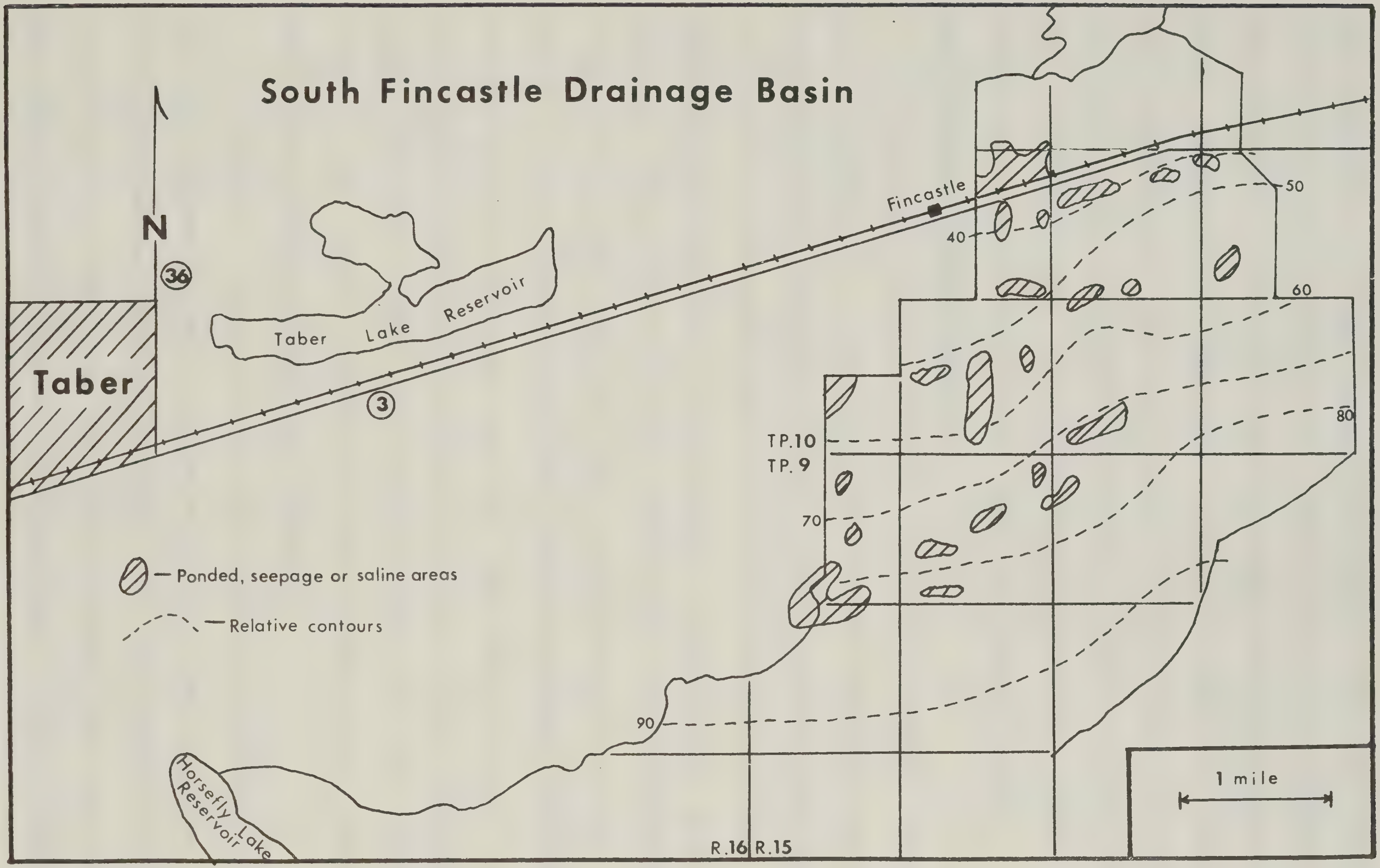

Figure 5.1. Ponded, seepage or saline areas and relative topography of S.F.D.B.

such a condition. The lateral movement of the water downslope along the contact of the underlying till can cause salt accumulations if the till contact comes within the capillary range. This could be the case in some of these wet areas. Also, the canals, which are located in this light-textured soil, could lose considerable amounts of water through seepage. This situation is very noticeable from the water distribution system map (Alta. Dept. of the Env. 1970).

Soil drainage classification

The soil drainage classes obtained for these soils are shown in table 5.1, along with some other important drainage characteristics. The north half of the drainage basin shown in figure 5.2 indicates that this area is mostly rapidly drained with some small areas rapidly to moderately well-drained. The southern part is classed as mostly well-drained to moderately well-drained. Many areas have a two-class rating. All of these soils have a better drained surface section than a subsurface section. The water movement downwards does not present a problem until the lesser drained section is encountered. The problem areas would be located mainly in the central portion of the drainage basin, where most of the shallow soils are situated.

The main concern in an area where two definite soil drainage classes exist for some soils, is checking the difference between the two classes. If, for example, the Purple Springs loamy sand soil is considered, the top section being rapidly drained would only mean a faster accumula-

Table 5.1

Some important soil characteristics for the soils in the S.F.D.B.

Soil series	Texture	Average till depth*	Topography	Irrigation rating	Hydraulic conductivity of subsoil	Drainage class
Chin	LtL, VFSL, L, SiL	4 feet	level to gently undulating	good to very good	moderately slow to slow	well
Cranford	L	2 feet	level to gently undulating	fairly good to good	slow to very slow	well to moderately well
Bingville	SL, FSL	5 feet	level to undulating	good to very good	moderately slow to slow	well to moderately well
Cavendish	LS	5 feet	level to undulating	poor to fair	moderately slow to slow	rapidly
Antonio	SL	2 feet	level to undulating	poor to fairly good	slow to very slow	well to moderately well
Purple Springs	LS	2 feet	level to undulating	poor to fairly good	slow to very slow	rapidly to moderately well
Maleb	L	4 feet	gently undulating to rolling	fairly good to good	moderately slow to slow	well to moderately well
Wardlow	L	4 feet for till, 1 foot Bnt horizon	level to gently undulating	fair	moderately slow to slow	moderately well

* or depth to impeding horizon

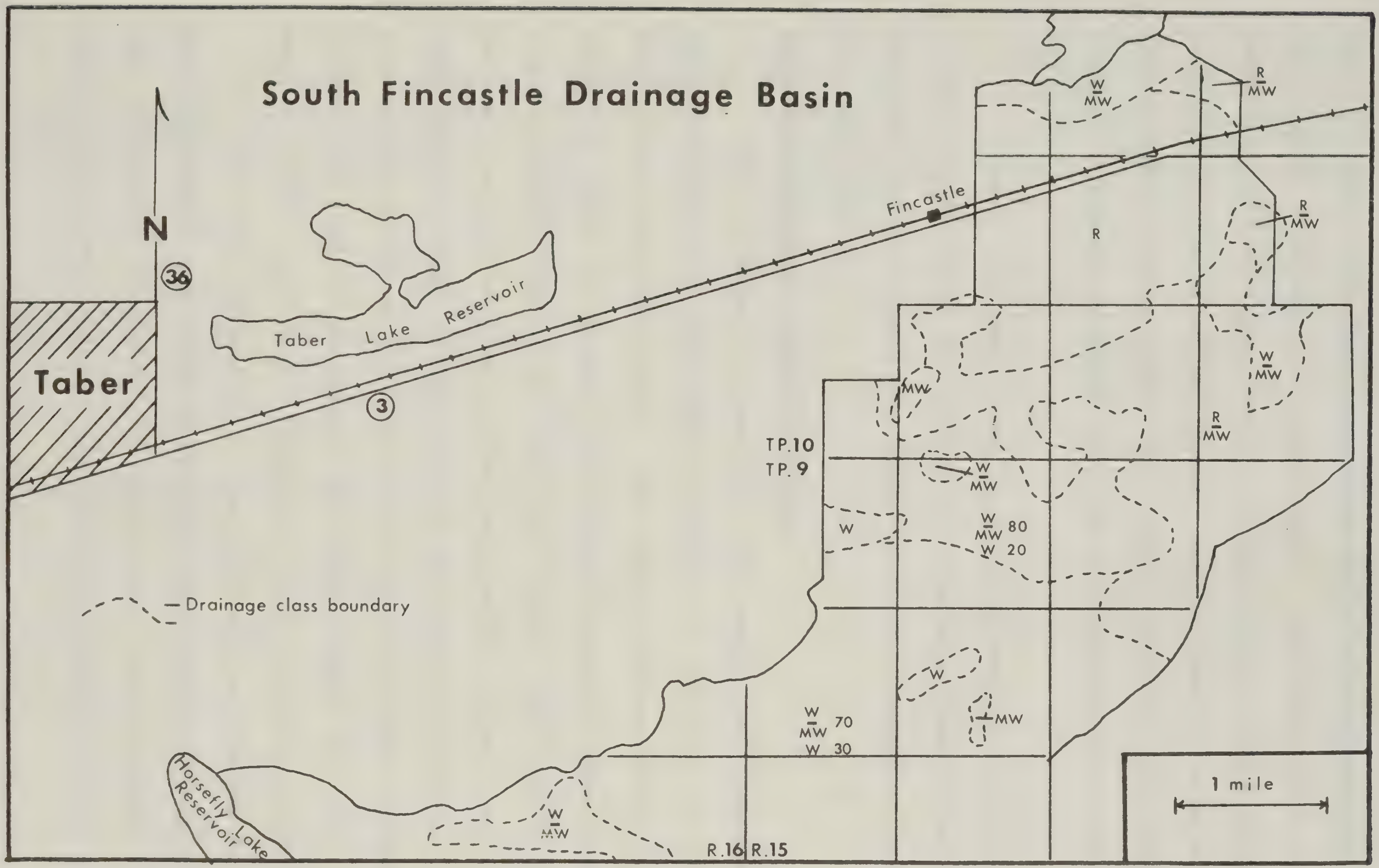

Figure 5.2. Soil drainage classification map of S.F.D.B.

tion of water over the moderately well-drained section. The result is evident in some cases. The soils that will have the most problems are the Purple Spring loamy sands, followed by the Cranford loams, Antonio sandy loams and the Bingville sandy loams. The other soils can also have certain drainage problems but the more susceptible ones are cited.

There are many other factors affecting the drainage as mentioned before but this soil drainage classification neglects most of these and deals with the virtually unchanging soil only.

Empirical drainage classification

The information used for this empirical drainage classification is presented in table 5.1 All of the listed soils have been described. The classification which is shown in table 5.2 groups the various factors, thus producing an average rating for each soil type. Each soil type has two ratings because of the topography factor. An empirical drainage classification map for the area is presented in figure 5.3. Since the soil drainage classification was used to determine the class ranges for the empirical drainage classification, they are very similar.

The shallow soils in the southern portion of the drainage basin are rated mostly as moderately well-drained. The topography is drastic in some cases, even placing the rating in a lower class. The drainage rating reveals the

Table 5.2

Empirical drainage classification for the soils in the S.F.D.B.

Soil series	Texture rating	Topography rating	Surface soil rating	Till rating*	Hydraulic conductivity rating	Subsoil rating	Basic soil rating	Drainage class
Chin	L 35	L 45	80	35	35	70	56	W
		GU 35	70				49	W
Cranford	L 35	L 45	80	15	15	30	24	MW
		GU 35	70				21	MW
Bingville	FSL 40	L 45	85	40	35	75	66	R
	SL	U 20	60				47	W
Antonio	SL 40	L 45	85	15	15	30	26	MW
		U 20	60				18	I
Purple Springs	LS 45	L 45	90	15	15	30	27	MW
		U 20	65				20	MW
Maleb	L 35	GU 35	70	35	25	55	39	W
		R 15	50				28	MW
Wardlow	L 35	L 45	80	15	25	40	32	MW
		GU 35	70				28	MW
Cavendish	LS 45	L 45	90	40	35	75	68	R
		U 20	65				49	W

* or depth to impeding horizon

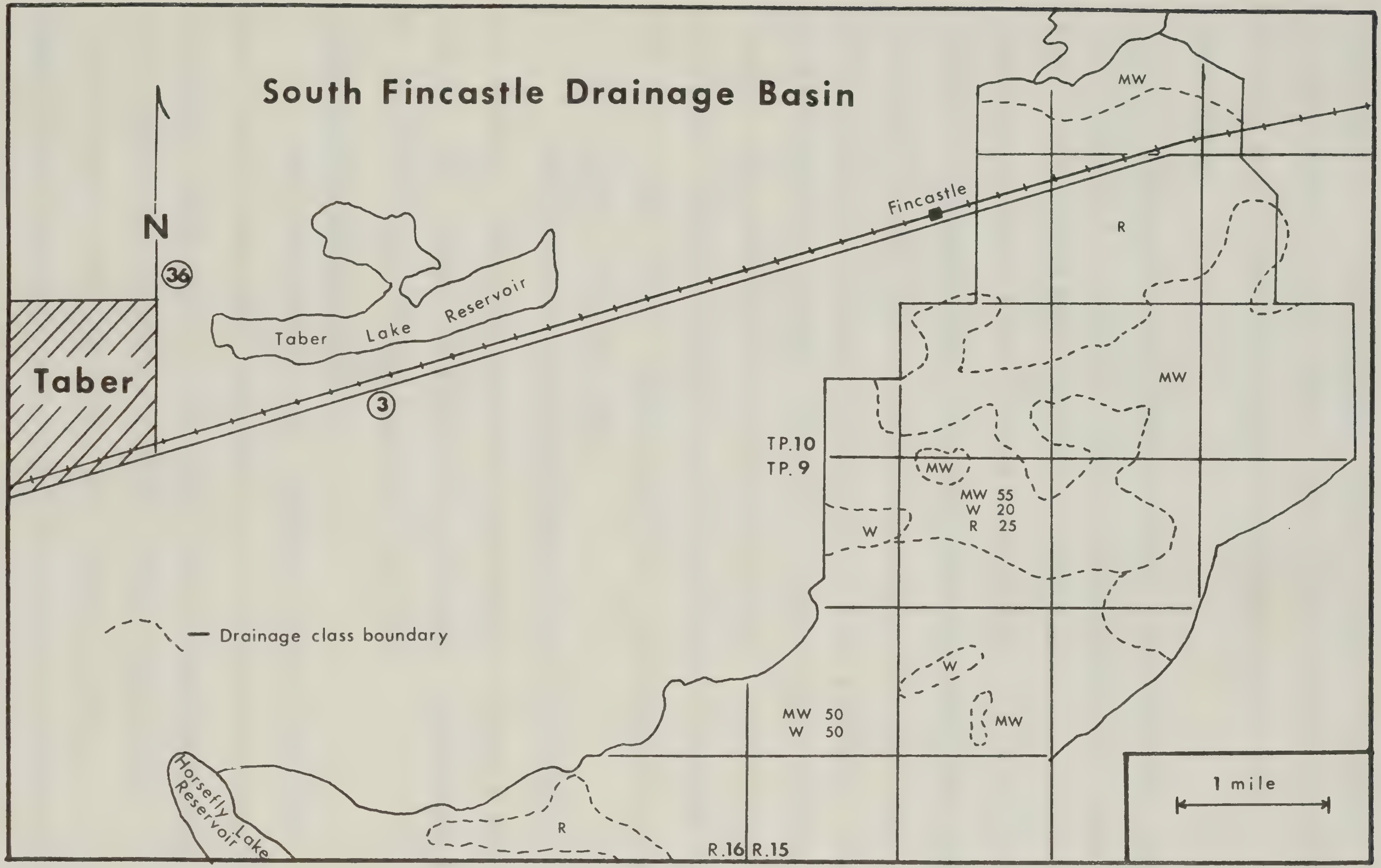

Figure 5.3. Empirical drainage classification of S.F.D.B.

importance of the topography factor. The soil survey report (Bowser et al 1963) mentions that some soil series do have saline and drainage problems because of the topography.

Moderately well-drained soils are borderline cases, therefore their condition may not always be very stable in time. Under variable irrigation conditions they could improve or become worse. This map (figure 5.3) aids in detecting these problem areas and offering some solutions. Topographically located above the rapidly drained area, the moderately well-drained soils present some problem. The spring water and summer irrigation waters are slow to move through this moderately well-drained area. By the time the water has moved laterally down to the rapidly drained soils, the hot summer air is drying the soil, leaving saline areas in the rapidly drained areas.

Since the soil characteristics will not change too rapidly, the only sensible solution is to adapt and improve the irrigation system in the area. Irrigation is to be used with, and not against, the soil.

<u>Water table classification</u>

The observation well readings in this drainage basin were summarized according to the previously described technique (table 5.3). The water table classifications were then obtained for each well. These water table classifications for each well are listed in table 5.4 and shown on the drainage basin map in figure 5.4 Each well

Table 5.3
Average water table depths below ground surface and standard deviation, in feet, for the wells in the S.F.D.B.

Well No.		Jan	Mar	May	Jul	Sep	Nov
1	mean	9.04	5.75	4.83	6.61	8.08	8.56
	s.d.	1.895	3.786	3.378	2.372	1.946	2.023
3	mean	5.25	4.23	3.07	3.84	4.39	4.66
	s.d.	1.040	1.530	.756	.935	.792	1.083
4	mean	5.35	4.08	2.82	4.03	3.96	4.71
	s.d.	1.450	2.482	1.947	1.769	2.347	1.473
5	mean	7.77	6.87	5.26	5.81	6.13	7.15
	s.d.	2.029	3.159	2.767	2.405	2.215	2.008
7	mean	5.15	3.36	3.11	3.96	4.72	4.72
	s.d.	1.066	1.973	1.440	1.298	1.699	1.218
8	mean	3.00	2.69	1.46	2.03	2.29	1.90
	s.d.	.708	1.470	1.489	1.412	1.528	1.554
11	mean	8.95	8.08	6.19	7.28	8.73	9.42
	s.d.	1.504	2.312	2.466	1.714	1.523	1.174
12	mean	6.34	4.98	3.55	4.55	5.23	5.14
	s.d.	1.408	2.170	1.562	.828	1.083	1.822

Table 5.4

Water table classes for the wells in the S.F.D.B.

Well No.	Degree of fluctuation	Shallow depth	Time	Modification factor	Water table rating	Water table class
1	55	70	75	100	26	F
3	75	50	75	75	21	P
4	75	48	75	70	19	P
5	75	75	75	100	42	G
7	80	50	75	70	21	P
8	85	35	75	25	6	VP
11	65	80	75	100	39	F
12	70	55	75	85	25	F

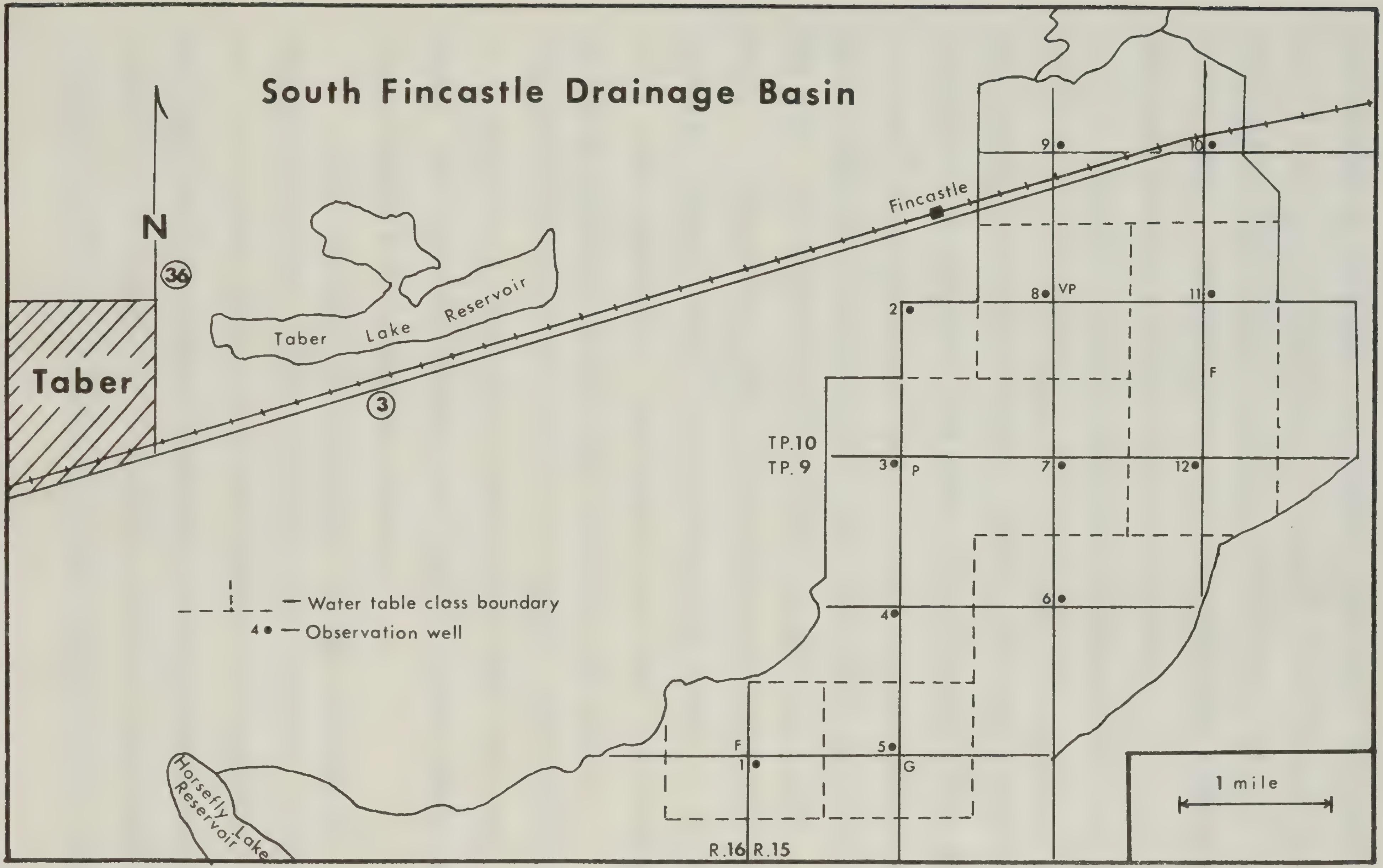

Figure 5.4. Water table classification map of S.F.D.B.

is assumed to represent one square mile which is outlined on the map by a dotted line. Adjacent areas having the same class were grouped together to produce a single larger area. The wells that were omitted when summarizing the data could not be included in this map.

The worst area is represented by well No. 8. Most of the bi-monthly averages for this well are close to two feet below the ground surface. This area definitely has a water table problem. Adjacent to this area, wells No. 3,4 and 7 were classed as poor. In this area, the water table depth can remain at less than four feet for part of the year. In future years an eventual problem could result. The central part of the basin should be investigated in greater detail to determine the causes of this water table condition. The areas rated fair are similar to the moderately well-drained areas in the other classifications. Under certain management there would not be a problem yet there is a possibility that one could exist. The area surrounding well No. 5, being rated as good, presents no immediate problem.

From this map an indication of the problem is definitely visible. The areas of lower elevation have built up a water table which has become quite serious. Of the wells tested, half of them had a water table classification of either poor or very poor. The drainage basin as a whole represents a drainage problem and certainly requires

additional attention.

5.2.2 MacLaine drainage basin

Aerial photograph interpretation

A map showing the wet areas is presented in figure 5.5. The term 'wet areas' will be used in lieu of ponded,seepage or saline areas.The distribution of wet areas is fairly even except for a slight concentration near the west end of the drainage basin. The 25-foot contour lines (Nielsen 1968) were superimposed on the area to further investigate these wet spots. The western portion has an irregular topography, sometimes quite steep. This could explain the more numerous wet areas on the western side. The other scattered wet areas could indicate only that the problem is local and not regional.

The heavier textured soils (SiCl, CL) and medium textured soils (SiL, L) do not present any obvious differences as far as wet areas are concerned. The differences could lie deeper in the soil profile. The Coaldale silty clay loam soils are deep while the Lethbridge silty loam soils possess a glacial deposit which averages five feet in depth. This till can affect the internal drainage while the deep Coaldale silty clay loam soils have more or less uniform drainage throughout the soil profile. The aerial photograph interpretation reveals that the rougher topography combined with the glacial till could present some drainage problems in this area.

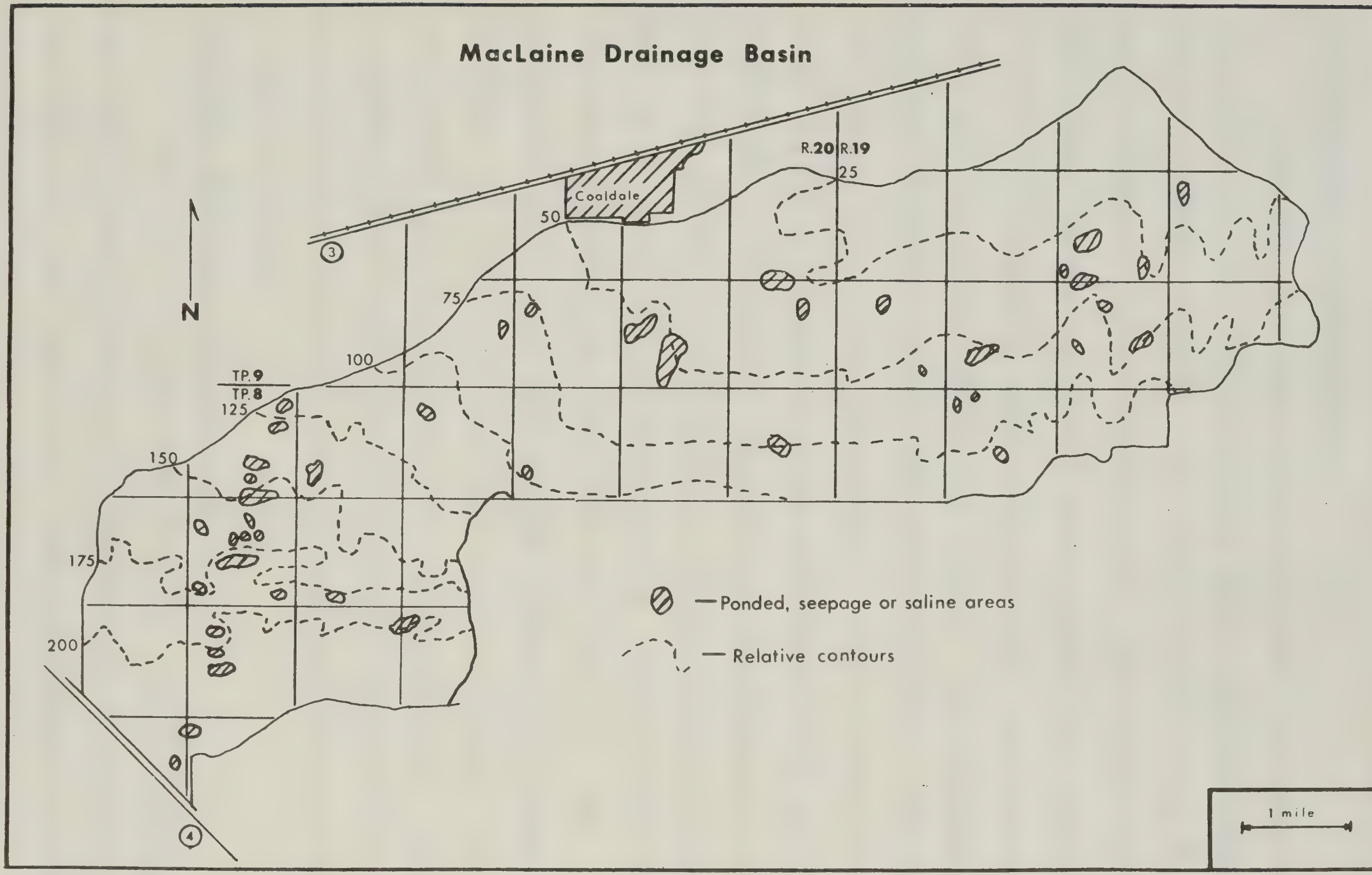

Figure 5.5. Ponded, seepage or saline areas and relative topography of M.D.B.

Soil drainage classification

The soil drainage classes obtained for these soils are shown in table 5.5 along with some other important drainage characteristics. The eastern half of the drainage basin is mainly classed as moderately well-drained while the western portion is mainly well-drained (see figure 5.6). The differences here are due to the two general soil textures of the area, heavy and medium. This indicates that the Lethbridge silty loam soils are better drained than the Coaldale silty clay loam soils. This is true if no other factor is considered such as depth to till and topography. The uniform texture of the Coaldale silty clay loam profile should provide better drainage conditions when the water is in the soil profile. The problem then is the penetration of the water into the soil. In the Lethbridge silty loams the reverse situation is present. The water can penetrate more readily into the soil but then the glacial till prevents further rapid drainage. When irrigating these soils, the main concern should focus on the system of irrigation used and the efficiency of the irrigation system.

Empirical drainage classification

From the data obtained from the soil survey report which are listed in table 5.5, the ratings of each soil were obtained (see table 5.6). The map produced from these ratings is shown in figure 5.7. This map is almost

Table 5.5

Some important soil characteristics for the soils in the M.D.B.

* or depth to impeding horizon

Soil series	Texture	Average till depth*	Topography	Irrigation rating	Hydraulic conductivity of subsoil	Drainage class
Lethbridge	SiL, L	5 feet	level to gently undulating	very good	slow	well
Whitney	SiL, L	shallow	level to gently undulating	fair to good	slow to very slow	well to moderately well
Coaldale	SiCL, CL	10 feet	level to gently undulating	good	slow to very slow	moderately well
Shallow Coaldale	SiCL, CL	shallow	level to gently undulating	fair to good	slow to very slow	moderately well
Readymade	CL,L	variable till depth	level to gently undulating	fair to good	variable	well to moderately well

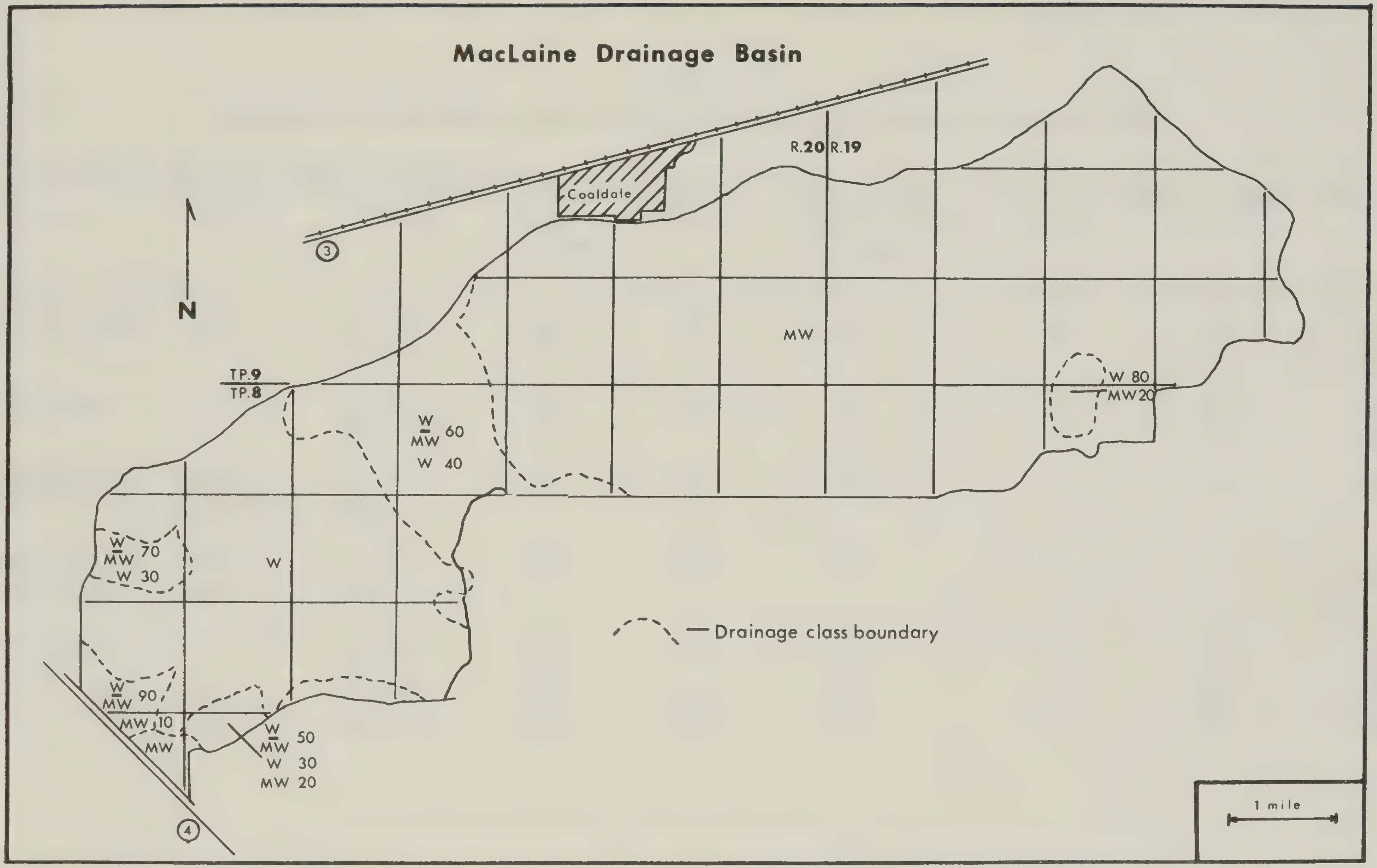

Figure 5.6. Soil drainage classification map of M.D.B.

Table 5.6

Empirical drainage classification for the soils in the M.D.B.

* or depth to impeding horizon

Soil series	Texture rating	Topography rating	Surface soil rating	Till rating*	Hydraulic conductivity rating	Subsoil rating	Basic soil rating	Drainage class
Lethbridge	SiL 35	L 45	80	40	25	65	52	W
	L	GU 35	70				46	W
Whitney	SiL 35	L 45	80	15	15	30	24	MW
	L	GU 35	70				21	MW
Coaldale	SiCL, CL 25	L 45	70	20	15	35	25	MW
		GS						
Shallow Coaldale	SiCL, CL 25	L 45	70	15	15	30	21	MW
		GS						
Readymade	L 35	L 45	80	35	25	60	48	W
		GU 35	70				42	W
	CL, HvL 25	L 45	70	35	25	60	42	W
		GU 35	60				36	MW

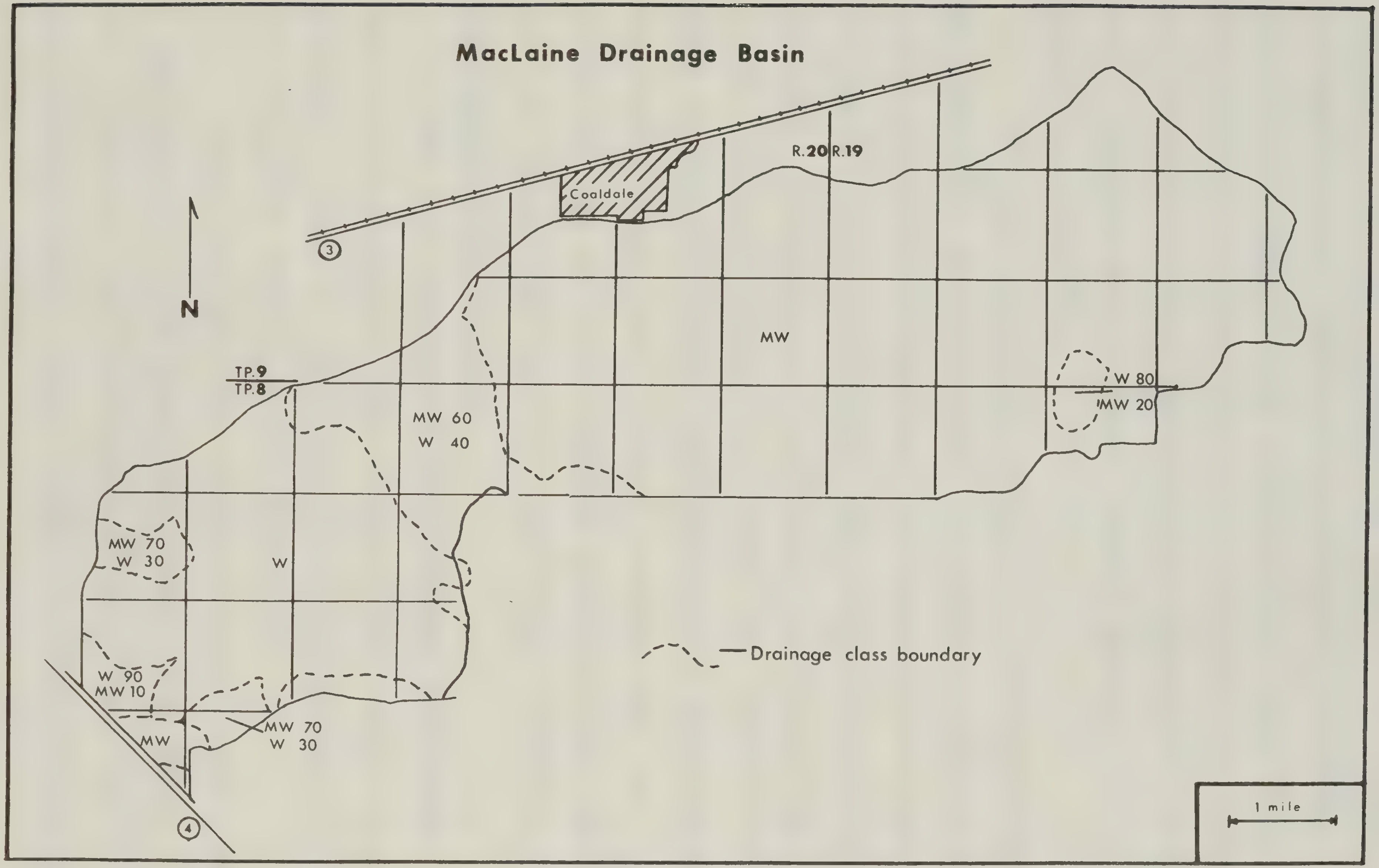

Figure 5.7. Empirical drainage classification map of M.D.B.

identical to the soil drainage map (figure 5.6). This would mean that the two factors previously discussed (depth to till and texture) probably cancel each other out. Even though the Coaldale silty clay loams possess more uniform internal drainage, rapid initial drainage of the upper profile accompanied by uniform internal drainage is often better for irrigation.

For this drainage investigation technique to be more effective, detailed rather than general descriptive information would be required. For example, more accurate till depths would mean another more precise definition of the depth to till factor. Similarly, the same can be done for the hydraulic conductivity. These new definitions cannot be used on a large scale basis since the division of the areas would be too small. With a 'general idea' map produced by the empirical drainage classification, smaller areas can be selected and then studied more carefully.

Water table classification

The well readings in this drainage basin were summarized according to the technique that was previously described. Table 5.7 lists the bi-monthly averages of each well along with their standard deviation.

Using this data, the wells were then rated. Most of the wells are rated from fair to good (see table 5.8). Well No. 2 was rated poor and wells No.9 and 13 were rated very poor. These three wells were located on the

Table 5.7
Average water table depths below ground surface and standard deviation, in feet, for the wells in the M.D.B.

Well No.		Jan	Mar	May	Jul	Sep	Nov
1	mean	5.89	4.36	4.59	5.01	5.68	5.69
	s.d.	.908	1.227	1.265	.631	.551	.821
2	mean	4.70	3.47	3.34	3.49	4.13	4.67
	s.d.	.897	.529	.783	1.111	.858	.768
6	mean	4.73	3.09	3.57	4.96	4.40	4.05
	s.d.	1.364	1.238	1.084	.653	1.189	1.639
7	mean	7.20	6.77	5.54	4.73	5.79	6.76
	s.d.	.791	.995	1.295	1.300	.584	.970
8	mean	6.58	4.09	4.20	7.42	7.31	6.43
	s.d.	1.462	.738	1.188	.646	1.517	1.500
9	mean	5.41	3.79	3.04	2.66	2.76	4.09
	s.d.	.753	.650	.765	1.358	.733	.834
11	mean	5.18	4.10	4.48	4.39	5.44	5.02
	s.d.	1.616	.756	1.024	1.403	2.218	2.169
12	mean	5.42	3.74	3.67	4.40	4.46	4.70
	s.d.	1.708	1.904	1.635	2.085	1.595	1.323
13	mean	4.30	2.12	2.65	2.21	2.28	3.32
	s.d.	.684	.308	.600	.588	.518	.831
14	mean	5.73	4.82	5.07	5.95	5.84	6.06
	s.d.	1.671	1.829	.911	1.446	2.575	1.781
16	mean	5.06	2.64	3.70	3.60	4.10	5.01
	s.d.	1.266	.699	.784	.354	.255	.425
18	mean	7.75	6.33	6.52	5.48	6.73	7.03
	s.d.	2.079	1.622	1.258	1.057	1.148	2.002
19	mean	4.59	3.38	3.98	3.49	3.76	4.24
	s.d.	.978	.409	.436	.726	.663	.195
20	mean	5.90	3.51	4.07	5.38	6.27	6.06
	s.d.	1.507	1.363	.805	.854	1.211	1.632
21	mean	9.71	9.65	9.08	8.35	8.88	9.15
	s.d.	.270	.430	.729	.486	.590	.424

Table 5.7 (continued)

Well No.	Jan	Mar	May	Jul	Sep	Nov
24 mean	6.83	6.05	6.52	6.58	7.02	6.95
s.d.	.666	1.054	1.234	.993	.850	.704

Table 5.8
Water table classes for the wells in the M.D.B.

Well No.	Degree of fluctuation	Shallow depth	Time	Modification factor	Water table rating	Water Table class
1	85	65	85	85	40	G
2	85	54	75	70	24	P
6	80	55	85	70	26	F
7	75	68	50	100	26	F
8	68	60	85	100	35	F
9	75	45	50	60	10	VP
11	85	63	85	85	38	F
12	83	55	75	75	26	F
13	78	40	85	50	14	VP
14	90	70	85	90	49	G
16	75	55	85	70	25	F
18	75	75	50	100	28	F
19	90	55	85	60	25	F
20	73	60	85	90	33	F

Table 5.8 (continued)

Well No.	Degree of fluctuation	Shallow depth	Time	Modification factor	Water table rating	Water table class
21	85	95	50	100	40	G
24	90	95	85	100	65	VG

Coaldale silty clay loam soil (see figure 5.8). The other wells were rated somewhat better. The Coaldale silty clay loam has a water table classification ranging from very poor (low) to good (high). In these areas, when assessing the drainage problem, this fact should be investigated further. Local effects such as canals nearby or poor irrigation efficiency can drastically change the water table near the well. With better management some areas can be improved.

The heavier textured soils in the east portion rate lower than the medium textured soils in this drainage basin. The Lethbridge loams react more favorably to the addition of irrigation water. However, the west portion of the drainage basin could be a possible problem area due to the topography.

The problem area in the east portion has a lower elevation than the better classed area. Some of the excess water of the upper regions probably flows towards the northeast region of the basin. The accumulation of water in that area can cause the water table level to rise. Without the Malloy drain passing along the northern boundary of the basin this problem could have been more serious Nielsen (1970).

The two wells that were rated very poor are not beyond improvement. The water table averages were always deeper than two feet. A local, on-the-field investigation

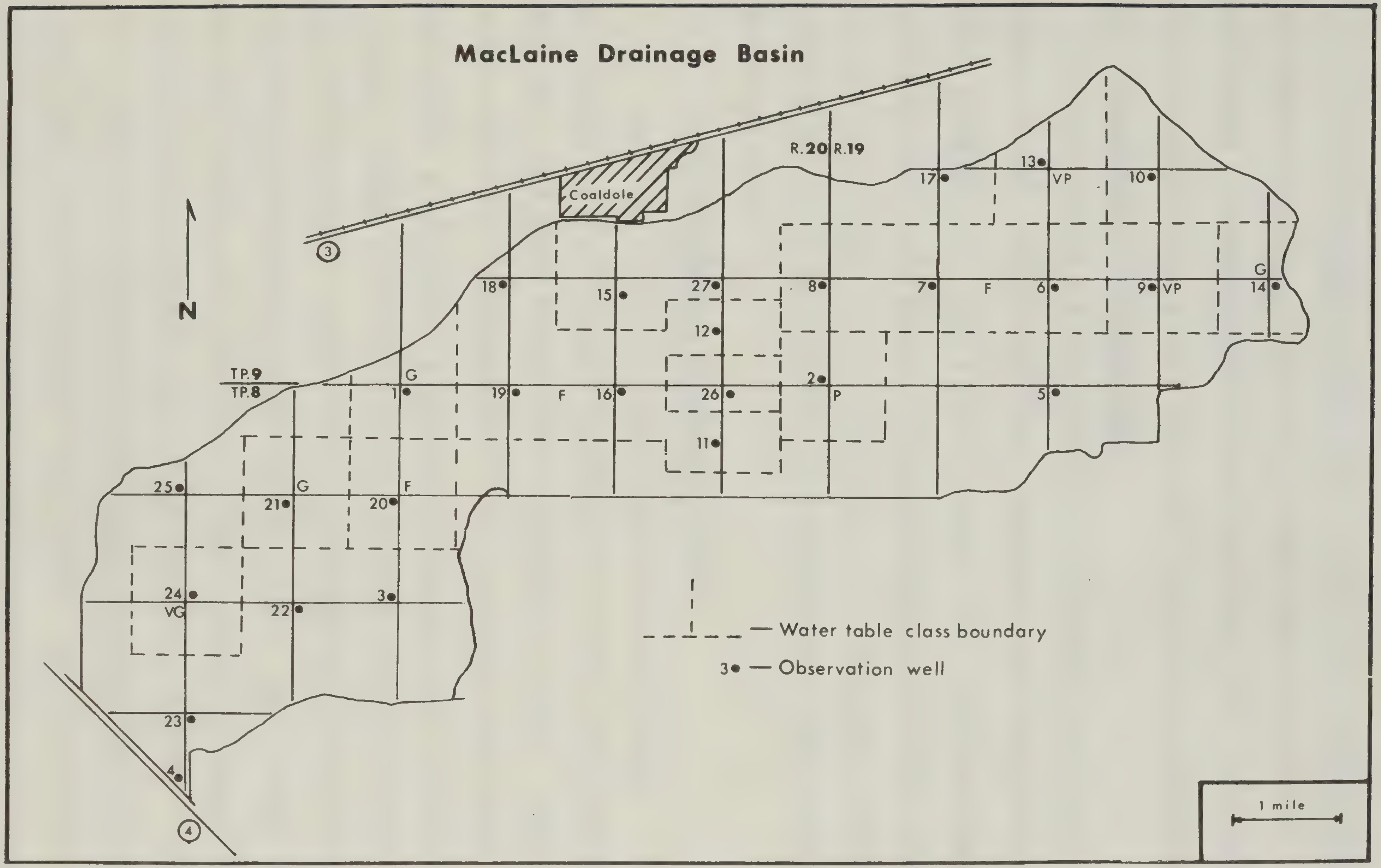

Figure 5.8. Water table classification map of M.D.B.

will probably suggest a solution since many factors are not considered here, such as a nearby canal or local topography. Nevertheless, the areas that are 'in trouble' can be located and a more detailed study can be undertaken.

5.3 Comparing the Techniques

The value of the methods can be justified only by comparing the results of each technique and obtaining some final conclusions. As stated before, the analyses cannot be separated since often one method depends on the other. The final drainage classification is to assemble all of the conclusions from each method and determining the severity of the problem.

5.3.1 South Fincastle drainage basin

Most of the wet areas found from the aerial photograph interpretation correspond to the areas where the very poor and poor water table conditions exist. This west central portion is composed of various soil types thus presenting a difficult problem in interpreting the drainage of these areas. Both the soil drainage class and the empirical drainage classification method show that this area is mostly a moderately well-drained area. This means that the soil moisture in excess of field capacity remains for a small but significant period of the year (C.D.A. 1970).

In the rapidly drained soils, such as the Cavendish loamy sands, many wet areas were found. This fact was mentioned in the soil survey report (Bowser et al 1963)

where the lateral movement of water along the till can cause some saline accumulations if the till depth is within the capillary range. Since there were an insufficient number of wells located in that soil type, the only immediate conclusion was provided by the aerial photographs. Even though the soil is rated as rapidly drained by the soil drainage map and the empirical drainage classification, the final conclusion however is that this area does have a drainage problem and a further investigation is warranted.

The small area of Wardlow loam, the only solonetzic soil, was found to be causing some salt accumulation near the surface. The aerial photograph indicated that in section 5, township 8, range 15, there was an area of salt accumulation. This area corresponds exactly with the small area of Wardlow loam. All solonetzic soils should be specially treated and careful attention should be given to them. This problem area can expand and cause problems in the surrounding areas.

The shallow soils, such as the Cranford loams and the Purple Springs loamy sands, are located on a slightly higher elevation than the rest of the basin. This must have an effect since both the water table classification and the wet area map indicate a fair to good water table condition and very few wet areas. The other two drainage maps indicate a moderately well-drained soil in that area. Therefore the higher elevation areas show that there is no immediate problem here.

5.3.2 MacLaine drainage basin

The water table classification, as mentioned before, reveals that the west portion has no water table problem. Yet from the wet, seepage and saline areas in the west portion, a drainage problem seems to exist. The topography is classed as gently sloping. The slope of the land either aids the water table movement or hinders local drainage. The two cases offer different results. This area is mapped as mostly well-drained by the two drainage classifications. The Lethbridge loams, which form most of this west portion, contain some salt in the Cca horizon. If the till depth is within capillary range, then salt accumulations appear at the surface. Other local conditions probably affect this local effect and a more detailed investigation would be very useful.

The moderately well-drained Coaldale silty clay loam covers most of the east portion. Wells No. 9 and 13, which are located at the most easterly part of the drainage basin, were rated as having a very poor water table condition. All of the water that is applied for irrigation eventually reaches the downslope position and builds up on the flatter areas. The Malloy drain, bordering the drainage basin, certainly aids in relieving this water build up. The heavy texture has caused a few wet areas to appear at the surface. As mentioned before, most of the west division of the St. Mary irrigation project is a recharge area and therefore

the water table should not become a problem. Irrigation and drainage practices should be special for this heavy-textured soil.

Chapter 6

SUMMARY AND CONCLUSIONS

1. Four drainage investigation techniques were developed in order to evaluate drainage problems on some southern Alberta irrigated soils. Two methods were interpretative while the other two were empirical.
2. Of the two interpretative methods, one used the soil survey report of that area to evaluate the drainage problem of the area while the other used aerial photographs. The soil survey report provided a base for all the other methods. The aerial photograph utilization proved quite useful and successful in detecting problem areas.
3. The empirical techniques examined the areas from two different points of view. The empirical drainage classification based on the Storie-Index, used only four selected characteristics related to the drainage of water in the soil. Since the data used was general, the result was also a general map. The water table classification made use of well records obtained from the Department of the Environment, Lethbridge, Alberta. Described by four physical factors and one modification factor, the water table classification shows areas that have a water table problem.

4. A statistical method for summarizing the water table data was developed. Since each well reading was taken at a two-month interval, bi-monthly averages were determined for each well after having discovered that the water table had a one-year cycle.
5. Each drainage investigation was accompanied by a map which describes the problem visually. Each map was then carefully examined. Sometimes other features were included in the map, such as topographic contour lines. These added features were helpful in explaining some of the problems.
6. These four drainage investigation techniques were critically evaluated. The advantages and disadvantages were compared but the methods were not compared with each other. The known limitations of each drainage investigation will result in more conservative conclusions.
7. Two areas were then examined using these developed techniques. The South Fincastle Drainage Basin of the Taber Irrigation District and the MacLaine Drainage Basin of the St. Mary's River Irrigation District were chosen as the study areas. All of the necessary data and information was obtained for the areas. The soils that presented some problems were the Cavendish loamy sands and the Coaldale silty clay loams. No generalization could be made

from this since only two small areas were studied. The problem sometimes was due to location rather than soil type, which was the case for the Lethbridge loams. For studying small drainage basins and determining general drainage problems, these methods proved quite successful.

8. Since factors other than the soil were found to affect the general drainage problem, this would indicate that possibly some of the neglected factors, such as an irrigations system, water distribution system, etc., might influence the drainage problem.

9. By comparing the four drainage investigations for each area, often a problem area, such as an accumulation of wet areas, could be explained from the high water table or from a shallow profiled soil in that area.

10. The methods developed are not perfect for describing the drainage problem but they offer some way in which to obtain relatively quick and reliable information on irrigated soils in a particular location. The same soil in a different environment would probably react differently. This study was local yet provides general information for the two areas that were studied.

Chapter 7

RECOMMENDATIONS

This type of study usually does not offer any solutions to the problems encountered, yet this general investigation sometimes indicates the steps to be followed. The following are recommendations that would be helpful in studying local drainage problems.

1. The location of wells in a drainage basin is very important. If located for convenience rather than for accuracy, then the wells are not well situated. The well location should be at a distance from canals, borrow pits and roads. The best location is determined from the local topography. A grid in this case is not necessary.
2. The number of readings taken per year will depend on staff number, finances, etc., but an effort should be made to reduce the interval of readings from 2 months to 2 weeks, especially during the summer. The hydrographs produced will represent a truer water table position. The time interval should be kept as constant as possible. Another important parameter to record could be whether or not the farmer is irrigating at the time the reading was taken.
3. Water records and ditch-rider records vary from one project to another, and also from one ditch-rider

to the next. A standard form should be developed for all districts so that all ditch-rider records in every irrigation project will have the same format. Every detail should be mentioned from the stream size to the number of acres of crop being grown. Some projects provide this information but they lack organization.

4. More detailed soil information is a definite necessity. Areas that warranted further investigation will require more accurate soils data Part of this soil information is the depth-of-till to determine the till contours. Hydraulic conductivities of both the soil surface and the subsurface should be determined.

5. When checking a drainage problem in a small area (farm size) the first step is to evaluate the irrigation system efficiency. The most important part of the evaluation is to record the time the water is turned on to the land and the length of time it is applied. This added information could aid in explaining why a drainage problem occurs.

Chapter 8

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Appendix A

This appendix contains the profile descriptions of the soils in the two study areas. The information was obtained from Bowser et al (1963).

Table A1
Soil profile descriptions for soils in the S.F.D.B.

Soil name	Horizon	Variation in depth	Description
Cavendish LS,FSL, SL (Cd.)	Ah	0 - 4"	Dark greyish brown fine sandy loam (10YR 4/2). Loose with grass roots.
	AB	4 - 7"	Brown fine sandy loam, loose.
	Bm	7 - 20"	Brown sandy loam (10YR 4/3 - 5/3). Firm in exposed road cut.
	BC	20 - 40"	Yellowish Brown sandy loam to loamy sand (10YR 5/4), loose
	Cca	at 40"	Light yellowish brown (10YR 6/4).Loose. Low lime concentr ion.
	Ck	at 50"	Light yellowish brown loamy sand to sand. Loose under dry land conditions, often wet above the till contact.
Chin Lt.L,VFSL,L, (Ch.)SiL	Ah	0 - 4"	Brown loam (10YR 5/3). Granular to weakly prismatic.
	Btj	4 - 8"	Brown to dark brown loam to heavy loam (10YR 4/3 - 5/3). Prismatic; May be slightly stained on cleavage faces.
	B	8 - 15"	Brown loam. Prismatic, wider prisms than in horizon above.
	Cca	15 - 26"	Light brownish grey loam (10YR 6/2). Friable. Medium to heavy lime carbonate accumulation.
	Csk	at 48"	Yellowish brown loam to silt loam (10YR 5/4). Massive to blocky. Contains lime and usually some salt.

Table Al (continued)

Soil name	Horizon	Variation in depth	Description
Maleb L (Mb.)	Ah	0 - 4"	Brown loam (10YR 5/3). Loose in top portion and weak blocky towards the lower portion.
	Bt	4 - 12"	Brown to dark brown heavy loam to clay loam. Prismatic to weak columnar, breaking into subangular blocky aggregates.
	Cca	12 - 18"	A medium lime carbonate accumulation. Usually a low salt content.
	Csk	18 - 24"	Brown to olive brown clay loam till. Massive to large blocky.
	C	at 36"	Contains erratics of granite, ironstone, and coal.
Wardlow L (Wd.)	Ah	0 - 4"	Brown (10YR 5/2 - 5/3) silty loam. Weak platy to granular.
	Ae	4 - 6"	Brown to pale brown (10YR 5/3 - 6/3) loam, platy.
	Bnt	6 - 14"	Brown (10YR 5/2 - 4/3) clay loam to silty clay. Round or flat topped columnar. Strongly stained in the upper half of this horizon.
	Cca	14 - 24"	Pale brown silty clay loam. Weakly prismatic to large blocky. Medium (occasionally fairly high) lime carbonate accumulation.
	Csa	at 36"	Brown to yellowish brown clay loam. Massive. Somewhat saline.

Table A2

Soil profile descriptions for soils in the M.D.B.

Soil name	Horizon	Variation in depth	Description
Coaldale SiCL (Cdle.) CL	Ah	0 - 3"	Very dark greyish brown (10YR 3/2 - 4/2) silty clay loam. Granular.
	Bt	3 - 9"	Dark greyish brown (10YR 4/2) silty clay. Irregular prismatic. Some staining on the cleavage faces.
	Bm	9 - 16"	Greyish brown (10YR 4/2 - 5/2) silty clay. Wide irregular prismatic.
	Cca	16 - 24"	Medium lime accumulation
	Cksj	at 36"	Light brownish grey (10YR 5/2 - 6/2). Heavy silty clay loam to silty clay. Massive. Occasional small inclusion of salt crystals.
Lethbridge L, (Leth.) SiL	Ah	0 - 5"	Dark brown (10YR 4/2 - 3/3)light silt loam.
	Bt	5 - 10"	Brown to dark brown (10YR 4/2) silt loam, prismatic with some staining of the cleavage faces.
	Bt2	12 - 17"	Brown silt loam, prismatic, slight staining.
	Cca	17 - 30"	Weakly blocky silt loam. Medium to heavy lime carbonate content. Lower portion may contain some salt.
	Ck	at 36"	Yellowish brown loam. Massive.

Table A2 (continued)

Soil name	Horizon	Variation in depth	Description
Readymade L (Ry.)	Ah	0 - 3"	Dark greyish brown (10YR 3/2) loam. Loose platy.
	Bm	3 - 7"	Brown (10YR 4/3) silty loam. Prism.
	Ck	7 - 17"	Light brownish grey (10YR 6/2) silty loam to clay loam. Blocky single grain.
	C	at 20"	(10YR 7/2) loam to silty loam. Mass single grain.
Carmangay SL (Cm.)			Alluvial aeolian parent material.

APPENDIX B

This appendix contains some weather data on the two study areas, the Lethbridge Research Station, Lethbridge, Alberta, and Taber, Alberta.

Table B1

Monthly and annual total precipitation of rain and snow, inches of water at Taber, Alberta.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total
1962	.67	.65	.80	.35	1.33	1.11	3.33	.74	1.85	.48	.39	.43	11.53
1963	1.60	.89	.09	.42	.63	6.93	1.63	1.10	.83	T	.58	1.60	16.30
1964	.67	.55	-	2.35	2.86	1.60	1.07	.45	1.94	.09	1.07	2.61	
1965	.89	.90	.89	1.17	2.25	4.87	.75	2.09	2.26	T	1.78	.43	18.28
1966	1.20	.53	.64	1.97	1.87	4.73	2.62	2.60	.26	1.09	1.30	.63	19.44
1967	.65	.75	1.58	5.46	1.13	2.91	.84	.65	.11	.32	.44	1.62	16.46
1968	.48	.20	.52	1.74	1.41	2.61	.72	1.03	4.33	1.07	.22	2.08	16.41
1969	2.46	.99	.65	.26	.86	3.28	1.22	.18	.28	.67	.14	.17	10.86
1970	1.06	.43	.81	.75	.83	4.34	.32	.72	1.45	.46	1.25	.78	13.20
1971	2.98	.68	.48	.88	1.24	2.26	1.53	1.53	.47	1.08	.42	1.38	14.93
1972	1.60	.99	1.69	1.30	1.32	1.12	2.23	.74	1.98	.45	.05	1.75	15.22

Table B2

Monthly and annual total precipitation of rain and snow, inches of water at Lethbridge Research Station, Lethbridge, Alberta.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total
1965	.95	1.16	.97	1.23	1.88	5.79	2.25	2.07	2.80	.01	1.47	.49	21.07
1966	.84	.40	.65	1.54	2.52	4.69	3.75	2.40	.56	1.13	1.30	.71	20.49
1967	.42	.74	1.80	4.43	2.25	3.21	.06	.95	.60	.44	.62	1.34	16.86
1968	.53	.18	.33	1.59	1.69	2.76	.72	1.94	3.84	.66	.08	1.29	15.61
1969	1.42	.47	.40	.55	1.26	5.01	1.35	.06	.66	.55	.02	.15	11.90
1970	.95	.52	.91	1.19	1.29	3.41	.63	.59	1.50	.45	.92	.52	12.88
1971	1.44	.91	.58	.90	1.62	2.70	1.82	1.54	1.07	1.22	.25	.99	15.04
1972	1.57	.54	2.15	.94	1.10	1.64	2.10	.31	1.39	.56	.01	1.14	13.45

Table B3
Monthly mean maximum and minimum observed temperature, degrees Fahrenheit, Taber, Alberta.

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1962	max	-	20.1	32.6	62.0	-	-	-	-	69.0	61.4	48.8	37.2
	min	-		10.7	34.3	-	-	-	-	40.5	36.9	26.9	16.2
1963	max	21.1	38.9	48.5	56.1	64.9	71.4	78.7	78.4	76.6	65.5	43.7	28.3
	min	-.3	-	26.3	31.4	40.3	48.9	51.6	52.5	47.4	38.7	19.2	7.4
1964	max	32.8	44.0	37.1	53.0	62.9	72.8	81.5	74.8	60.8	63.6	38.7	10.9
	min	12.8	20.6	13.4	29.5	41.8	48.6	52.5	48.9	40.0	36.3	18.0	-8.3
1965	max	21.7	31.5	29.9	51.9	62.2	68.6	79.5	78.0	54.1	65.2	34.6	28.1
	min	-2.6	7.8	9.0	30.4	40.3	47.6	53.8	52.7	35.0	37.1	12.6	11.4
1966	max	13.9	30.4	47.5	51.1	68.1	69.0	79.2	75.1	73.9	55.7	33.8	31.8
	min	-10.1	7.6	20.9	26.8	40.9	46.8	50.7	48.5	44.4	32.6	12.4	10.7
1967	max	27.0	36.0	33.0	42.8	59.3	70.2	81.4	82.3	79.0	59.7	43.1	30.5
	min	3.8	12.2	12.0	21.4	38.4	47.3	52.6	51.5	47.5	34.6	21.0	8.5
1968	max	24.6	39.2	52.1	52.7	62.7	70.4	78.2	72.6	-	56.5	43.4	19.5
	min	4.0	11.9	26.4	28.3	37.3	46.7	49.7	47.1	-	33.5	23.3	.6
1969	max	-2.7	21.9	36.7	60.4	68.1	70.7	77.5	83.9	70.7	47.8	52.0	37.3
	min	-21.0	-.8	11.9	34.9	41.8	47.0	51.2	50.2	42.9	26.7	26.0	16.0
1970	max	17.9	37.4	38.4	50.6	67.8	78.3	82.6	83.3	66.1	55.5	32.8	23.8
	min	-.2	15.4	15.3	30.1	41.4	54.0	54.7	51.2	40.2	31.1	13.9	2.8
1971	max	18.7	35.7	38.6	56.8	67.5	72.1	79.2	87.1	65.8	54.8	39.5	20.2
	min	-4.3	17.7	17.6	31.0	41.6	48.9	51.1	55.0	39.3	30.6	21.3	-2.9
1972	max	15.2	19.8	43.0	53.6	60.5	75.6	73.4	81.4	59.5	53.4	42.0	23.4
	min	-3.3	2.6	17.9	29.6	40.3	50.4	49.5	53.1	35.7	25.4	24.5	2.8

Table B4
Monthly mean maximum and minimum observed temperature, degrees Fahrenheit, Lethbridge Research Station, Lethbridge, Alberta.

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1965	max	24.0	34.0	31.0	53.0	61.0	68.0	78.0	77.0	52.0	64.0	35.0	29.0
	min	3.0	9.0	9.0	30.0	39.0	46.0	52.0	51.0	33.0	38.0	13.0	12.0
1966	max	17.0	32.0	47.0	51.0	67.0	68.0	76.0	73.0	73.0	55.0	34.0	33.0
	min	-8.0	9.0	21.0	26.0	39.0	46.0	50.0	47.0	44.0	34.0	13.0	12.0
1967	max	28.0	37.0	33.0	41.0	58.0	68.0	82.0	82.0	78.0	58.0	42.0	31.0
	min	5.0	13.0	14.0	21.0	37.0	46.0	51.0	51.0	47.0	35.0	21.0	9.0
1968	max	25.0	39.0	51.0	51.0	61.0	69.0	77.0	71.0	66.0	56.0	43.0	19.0
	min	3.0	14.0	26.0	28.0	37.0	47.0	49.0	47.0	43.0	33.0	21.0	-1.0
1969	max	-2.0	23.0	38.0	60.0	67.0	69.0	76.0	82.0	70.0	48.0	52.0	37.0
	min	-20.0	-1.0	12.0	34.0	40.0	47.0	49.0	50.0	42.0	27.0	26.0	16.0
1970	max	19.0	39.0	39.0	49.0	66.0	77.0	82.0	83.0	65.0	55.0	35.0	27.0
	min	1.0	16.0	16.0	29.0	40.0	52.0	53.0	48.0	40.0	30.0	13.0	5.0
1971	max	20.0	37.0	37.0	57.0	66.0	70.0	78.0	86.0	63.0	53.0	39.0	20.0
	min	-2.0	18.0	16.0	31.0	40.0	47.0	49.0	54.0	39.0	31.0	21.0	-3.0
1972	max	15.0	23.0	42.0	51.0	65.0	75.0	73.0	81.0	59.0	53.0	41.0	24.0
	min	-4.0	4.0	17.0	28.0	39.0	49.0	49.0	52.0	36.0	24.0	24.0	4.0

APPENDIX C

This appendix contains the water table data as provided by the Alberta Department of the Environment, Lethbridge, Alberta.

The following abbreviations were used in the tables:

dry - observation well was dry

frz. - water was frozen

rep. - observation well was replaced

des. - observation well was destroyed

sur. - water table was at the surface

Table Cl

Water table depths from ground surface, in feet, for the period of 1962 to 1973 inclusive for the S.F.D.B.

Well No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						1962						
1				5.64		9.44		10.53		11.73		12.08
2		5.48				3.33		dry		3.53		4.08
3		4.66		2.81		4.49		3.46		4.88		5.43
4		9.42		3.91		5.66		6.32		5.66		6.26
5		dry		dry		dry		dry		dry		dry
6		dry		dry		dry		dry		dry		dry
7		6.24		3.74		5.47		5.67		5.22		5.17
8		4.72		4.15		4.66		4.56		4.22		3.92
9		6.36		6.21		4.09		3.72		3.65		4.10
10		dry		dry		dry		dry		12.99		11.79
11		12.28		10.13		10.50		9.75		10.55		10.55
12		6.05		2.84		2.64		5.58		5.94		6.49
						1963						
1		12.13		10.23		11.03	9.63	9.13		11.33		12.23
2		3.63		3.23		3.23	2.68	dry		3.25		dry
3		5.03		3.73		4.73	1.79	3.73		5.43		6.34
4		6.36		4.96		.56	.42	3.76		.68		3.96
5		dry		10.17		10.17	10.54	8.87		10.57		11.47
6		dry		dry		dry	dry	dry		dry		dry
7		4.42		4.12		5.42	1.35	2.62		5.44		5.62
8		3.42		2.52		3.72	2.06	1.62		3.64		3.92

Table Cl (continued)

Well No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
9		1.65		3.75		4.05	.73	3.35		3.70		4.55
10		7.39		6.89		7.69	6.16	3.79		6.24		5.69
11		9.45		8.25		8.25	5.50	5.85		9.11		10.16
12		3.64		4.94		3.34	3.19	4.54		7.64		dry
						1964						
1		12.35		11.35		9.05		10.25		9.95		9.60
2		dry		dry		2.45		4.30		3.25		4.10
3		5.65		4.75		3.75		6.05		6.35		6.45
4		3.45		3.55		4.25		4.45		5.35		5.85
5		12.00		8.90		7.40		9.40		10.20		10.75
6		dry		dry		dry		dry		dry		dry
7		5.55		4.90		3.75		6.75		5.65		5.50
8		3.50		3.80		1.85		4.60		3.40		3.20
9		5.05		4.90		2.65				4.35		5.10
10		5.05		6.54		4.95		7.65		7.25		6.60
11		9.85		9.20		7.85		10.45		11.05		10.95
12		dry		7.84		5.60		6.25		7.85		7.30
						1965						
1		10.65		.45		5.15		6.25		6.15	6.30	
2		dry		2.10		1.90		dry		3.63	3.20	
3		7.35		.15		4.05		4.55		3.90	4.75	
4		5.85		sur.		3.75		sur.		3.55	4.25	
5		10.70		5.10				9.60		5.70	7.00	
6		dry		dry		dry		dry		dry	dry	
7		6.15		.85		3.55		4.15		4.20	4.60	
8		3.90		3.80		2.05		3.85		1.50	2.00	

Table C1 (continued)

Well No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
9		5.75		.95		3.85		sur.		3.35	4.05	
10		6.55		1.55		3.95		4.50		4.95	3.95	
11		10.95		4.35		5.95		7.20		9.15	9.15	
12		7.75		1.55		4.65		5.45		4.75	4.20	
						1966						
1	8.30		sur.	1.25	2.65	2.95		2.95		7.75		7.35
2			4.40	dry	2.40	3.80		dry		dry		dry
3	4.05		6.45	3.85	2.45	2.65		3.85		3.05		3.35
4	5.15		sur.	.55	1.35	3.35		sur.		.55		3.65
5	8.50		9.00	9.20	7.50	5.80		6.10		6.30		7.60
6	dry		dry	dry	dry	dry		dry		dry		13.10
7	5.75		sur.	.65	2.15	2.45	3.65	1.40		1.85		2.95
8	3.40		4.40	2.00	.30	1.00		2.80		2.50		1.60
9	5.55		sur.	4.85	3.05	3.65		4.95		2.70		frz.
10	4.55		5.20	2.85	1.95	2.55		3.85		3.25		2.95
11	9.35		9.25	5.80	6.15	6.85		8.85		9.65		8.65
12	6.80		6.55	2.65	2.65	3.15		4.15		4.85		4.65
						1967						
1	7.45		2.95		1.55		3.95		8.05		8.35	
2	dry		dry		3.30		dry		dry		dry	
3	3.95		3.45		2.55		4.05		4.65		5.35	
4	2.85				sur.		3.55		.95		4.15	
5	7.50		6.20		1.30		3.70		5.80		6.80	
6	dry		dry		6.50		8.30		11.00		10.70	
7	3.05		2.25		.85		3.75		6.65		6.25	
8	1.80				.10		2.70		4.00		3.40	

Table C1 (continued)

Well No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
9	frz.		frz.		1.65		4.15		6.45		6.05	
10	3.25		3.35		1.75		3.05		6.85		6.75	
11	7.95		8.25		1.85		4.15		8.95		9.75	
12	5.15		3.55		.65		4.35		4.05		2.15	
						1968						
1	8.55		5.55		4.45		6.75		8.75		5.75	
2			dry		4.20		dry		dry		dry	
3	6.05		4.25		3.05		4.15		5.35		3.55	
4	4.05		4.55	3.95	2.65		5.05		5.95		4.15	
5	6.90		3.60		5.20		5.00		5.20		5.20	
6	11.60		11.30		11.00		10.70		9.80		7.40	
7	6.25		5.35		3.75		4.65		5.75		3.75	
8	3.90		3.40		1.30		3.10		2.50		.20	
9	6.25		5.85		4.25		5.05		3.35		2.95	
10	6.55		6.15		4.95		5.85		rep.		rep.	
11	10.05		7.65		6.25		7.15		9.45		8.25	
12	5.15		3.45		2.95		4.95		4.95		2.95	
						1969						
1	6.25		2.15		2.15		4.95		6.45		7.65	
2	dry		3.00		3.90		dry		dry		4.90	
3	4.85		1.95		2.35		4.05		3.65		4.95	
4	4.95		sur.		.55		4.55		4.65		6.30	
5	5.90		1.10		1.90		4.80		3.78		5.90	
6	8.20		9.60		7.10		8.10		3.10		8.00	
7	4.85		1.35		2.25		3.65		4.85		4.45	
8	2.10		sur.		.20		.60		.40		1.20	

Table C1 (continued)

Well No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
9	4.35		frz.		2.75		4.85		4.25		3.45	
10	dry		dry		dry		rep.		5.75		3.25	
11	7.75		5.65		4.25		6.05		5.55		9.75	
12	5.25		.55		1.95		5.05		3.35		5.05	
13					10.05		10.10	10.10	10.15		11.15	
14					7.55		4.05	8.85	6.25		11.05	
						1970						
1	7.85	8.35			6.15		6.95		9.25		9.75	
2	dry	dry			5.00		dry		dry		4.95	
3	5.55	6.45			3.95		4.55		4.15		4.75	
4	6.55	6.95			6.15		5.55		7.45		6.15	
5	7.00	7.60			6.50		6.10		4.40		6.70	
6	8.40	9.60			9.20		8.30		8.00		7.00	
7	rep.	rep.						5.10	5.60		4.50	
8	2.50	2.90			1.20		1.60		.60		.20	
9	4.45	4.65			3.45		1.35		.55		2.65	
10	4.65	5.25			3.55		2.55		5.65		5.15	
11	9.75	9.75			9.35		9.35		10.15		10.15	
12	5.85	5.95			4.65	rep.	rep.	4.70	5.40		5.70	
13	11.35	11.45			11.45		11.35		11.45		11.65	
14	11.55	11.75			8.15		11.85		11.95		12.35	
						1971						
1	10.05		1.95		3.55						7.75	
2												
3	5.75		2.35		2.75		4.45		4.05		4.35	
4	8.05				2.35		4.95		3.55		5.15	

Table C1 (continued)

Well No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
5	7.40		5.60		4.40		2.80		4.00		6.10	
6	8.60		8.00		7.20		7.90		8.00		7.00	
7	5.60		3.20		2.90		4.40		5.10		4.50	
8	2.80				sur.		sur.		1.30		.60	
9					rep.		3.25		5.95		6.35	
10	6.35		2.75		2.85		1.55		5.35		4.55	
11	6.35		2.45		3.85		6.35		8.85		9.55	
12	7.10		4.60		4.60		5.40		6.50		6.30	
13	11.85		11.35		11.45		11.55		11.55		11.55	
14	12.55		7.55		8.45		rep.		rep.		rep.	
						1972						
1	8.35		8.95		sur.		5.75		7.45		7.62	
2												
3	5.85		6.75		2.55		3.25		3.85		2.95	
4	5.65		6.75		1.75		5.15		5.75		5.75	
5	6.80		7.60		2.60		3.90		4.80		5.30	
6	8.00		9.20		6.40		7.00		6.80		5.70	
7	5.80		6.10		2.90		3.60		4.50		3.60	
8	3.10		3.50		.10		sur.		sur.		sur.	
9					3.35		5.95		7.35			
10	6.05		6.45		2.36		2.55		3.15		3.55	
11	9.55		9.85		4.55		7.65		7.25		6.65	
12	7.10		7.90		3.90		3.70		4.80		4.30	
13	11.55		11.55		10.25		10.65		10.95		11.25	
14	11.85		12.15		8.05		8.65		9.25		9.75	

Table C1 (continued)

Well No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						1973						
1	8.15		5.95		6.25		8.45					
2	5.70		5.90		4.30		5.00					
3	3.55		2.95		3.05		2.85					
4	5.75		5.55		5.65		5.25					
5	5.30		5.00		3.90		4.20					
6	7.00		7.30		5.70		6.60					
7	4.50		4.50		3.90		4.40					
8	2.50		1.30		1.10							
9	3.85		frz.		5.85		dry					
10	3.15		3.55		3.75		1.35					
11	6.75		6.95		6.05		7.45					
12	5.30		5.30		4.60							
13	11.35		11.45		11.45		11.05					
14	9.15		8.65		8.15		8.75					

Table C2
Water table depths from ground surface, in feet, for the period of 1964 to 1973 inclusive for the M.D.B.

Well No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						1964						
1						4.50		5.85		5.05	5.20	
2						1.00		3.25		4.15	4.25	
						1965						
1		5.25	2.15	3.75		3.85	3.95		4.80		4.95	
2		4.45	3.05	3.45		3.25	4.05		3.35		4.95	
3							4.20		5.00		des.	
4							4.00		4.60		4.20	
						1966						
1	5.45	6.35	5.15		4.35	3.85		5.45		5.05	4.95	
2	4.55	5.15	3.85		3.15	2.75		4.55		3.70	4.05	
3						6.30	5.20	3.90		dry	dry	
4	4.51	5.10	5.60		2.80	3.10		4.90		4.30	4.80	
5								6.30		7.10	6.20	
6								1.90		2.10	2.00	
7								5.90		7.45	7.90	
8								6.60		6.90	5.30	
9								3.85		4.05	4.45	
10								3.70		4.30	4.80	

Table C2 (continued)

Well No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						1967						
1	4.65		5.35		2.25		4.85			6.15	6.45	
2	4.05		3.75		1.95		4.55			5.25	5.45	
3	dry		dry									
4	4.30		4.70		1.80		4.80			dry	dry	
5	5.20		4.40		.80		4.40			5.80	5.90	
6	2.70		frz.		1.30		5.10			5.90	6.80	
7	7.70		7.80		2.70		6.00			5.00	6.30	
8	5.40		4.60		2.40		8.20			9.90	9.00	
9	4.45		4.85		2.15		5.65			2.85	5.65	
10	4.70		4.70		3.30		4.50			4.40	5.60	
11				3.85	2.65		5.65			8.25	8.55	
12					1.05		4.45			5.45	5.55	
13					1.55		2.05			2.25	3.05	
						1968						
1	6.85		5.25		4.65		5.25		6.15		5.05	
2	5.45		3.95		3.75		4.55		5.65		5.25	
3	8.40		7.50		6.30		7.20		8.10		6.40	
4	dry		dry		4.40		5.60		7.10		4.90	
5	6.50		3.50		2.20		4.40		5.00		3.60	
6	6.70		5.00		3.90		5.70		5.20		3.80	
7	6.60		6.70		5.40		6.30		5.50		5.00	
8	9.00		5.40		4.40		7.80		8.70		6.40	
9	6.45		4.45		3.65		1.95		2.75		4.35	
10	6.50		5.40		4.70		4.00		4.00		5.20	
11	8.15		5.45		5.05		5.15		5.05		3.65	

Table C2 (continued)

Well No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
12	6.05		6.15		3.45		7.95		6.45		5.35	
13	4.25		2.45		2.45		1.95		1.75		2.55	
14					4.70		5.50		1.10		3.50	
15					dry		dry	12.75	dry		dry	
16					2.80		3.60	3.30			5.00	
17					4.30		5.80		7.00		5.50	
18					4.85		7.45		7.45		5.95	
19					4.10		3.30		4.70		4.30	
20					3.00		4.60		5.50		4.10	
21					8.25		8.15		8.95		8.55	
22					7.70		9.20	10.40	11.60		9.20	
23							3.90	2.70	4.50		3.80	
24					8.35		8.15	8.05	8.35		7.75	
25					9.60		10.10		5.70		6.30	
						1969						
1		6.25	2.65		4.65		4.65			6.25	6.25	
2		5.65	3.25		4.75		4.35			4.25	4.85	
3		7.60	4.80		5.90		5.80			8.20	8.30	
4		5.70	5.40		5.00		3.20			5.40	6.30	
5		5.90	1.90		4.00		4.30			5.90	5.90	
6		5.40	3.00		4.20		4.70			3.00	4.20	
7		6.30	5.10		5.80		4.80			6.50	7.30	
8		6.80	3.10		5.50		7.80			5.50	5.50	
9		6.35	3.85		2.95		2.75			2.65	3.85	
10		7.20	4.30		4.60		4.30			4.20	5.10	
11		5.15	3.25		4.65		5.05			7.05	3.55	

Table C2 (continued)

Well No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
12		6.25	2.65		4.45		4.75			6.55	6.55	
13		5.45	1.85		3.25		3.45			2.55	2.95	
14		5.40	2.60		4.10		5.80			4.70	5.20	
15		dry	8.85		11.45		12.65			dry	dry	
16		6.70	1.40		3.90		3.70			4.90	5.50	
17		7.40	6.80		5.10		dry			8.90	dry	
18		7.55	4.55		6.45		5.05			6.95	7.45	
19		5.40	3.00		3.40		4.50			2.50	4.50	
20		5.50	1.90		4.10					4.70	4.90	
21		9.65	9.65		8.55		7.75			8.25	8.95	
22		9.70	6.90		4.60		4.20			8.70	8.70	
23		5.00	1.50		4.50		2.50			5.70	6.00	
24		7.55	6.45		6.45		6.35			6.95	6.95	
25		8.10	7.60		7.40		7.70			8.30	9.30	
26							4.25			3.65	3.45	
27								5.80		8.10	9.10	
						1970						
1	7.15		5.15		6.25			6.65		6.85	7.15	
2	5.95		3.75		2.95			4.55		4.65	5.55	
3	dry		8.10		7.30			7.50		8.00	8.00	
4	6.60		5.90		5.60					7.20	7.20	
5	7.00		4.70		5.10			6.30		6.00	6.00	
6	5.70		2.20		4.30			5.90		3.40	4.50	
7	8.10		6.90		6.20			3.50		6.50	7.30	
8	7.00		4.10		3.40			8.40		6.60	6.60	
9	6.15		3.45		2.25			1.65		2.35	3.85	
10	6.80		4.60		4.00							

Table C2 (continued)

Well No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
11	5.85		4.05		4.95			3.05		5.55	4.75	
12	7.55		4.55		6.05			3.95		2.95	3.05	
13	5.45		2.25		2.55			1.95		3.55	4.75	
14	6.40		6.50		5.80			6.40		5.50	6.20	
15	dry		11.45		dry			dry		dry	dry	
16	6.60		3.00		4.80			3.40		4.40	5.30	
17	dry		7.50		7.00					8.30		
18	9.05		7.65		8.65			4.15		8.55	5.95	
19	6.00		3.80		3.60			3.80		2.80	4.30	
20			4.50		4.60			7.10		7.00	7.20	
21	9.85		10.05		9.25			8.15		9.05	9.55	
22	9.50		7.30		7.20			10.70		dry	dry	
23	7.20		5.50		4.40					5.00	5.00	
24	7.15		6.95		6.95			6.95		7.45	7.45	
25	10.10		dry		dry			9.10		6.80	8.10	
26	5.35		3.85		4.35			2.15		4.35	4.95	
27	dry		8.20		7.70			7.20		8.10	7.20	
						1971						
1		6.55	5.05		6.15		5.25			6.15		6.15
2		4.85	4.05		3.35		1.75			4.35		4.75
3		8.10	6.80		6.80		7.40			7.80		7.70
4		6.70	5.70		5.70		5.90			7.30		7.30
5		3.40	4.30		4.70		4.60			6.50		6.30
6		3.70			4.30		5.50			4.90		4.80
7		7.50	6.50		6.30		3.40			7.00		7.50
8		6.70	4.00		5.40		6.60			8.40		6.80
9		5.95	3.25		4.25		1.85			2.45		4.35

Table C2 (continued)

Well No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10					4.80		4.40			4.80		5.80
11			3.55		4.85		1.55			1.95		3.95
12		2.15			3.75		2.55			2.95		4.95
13		4.05	2.35		3.35		2.15			3.05		4.65
14		1.80	3.10		5.20		7.00			7.60		7.80
15		dry	dry		dry		dry			dry		dry
16		3.10	3.00		3.90		3.00			4.80		4.90
17					6.90		6.50			6.80		6.30
18		6.35	5.95		6.95		4.55			10.45		10.25
19			3.50		4.50		3.10			3.60		4.40
20		5.70	4.10		4.60		6.40			8.20		8.00
21		10.15	9.65		9.65		9.15			9.95		9.15
22		dry	12.00		10.80		12.20			dry		dry
23		5.90			4.50					6.00		6.20
24		6.95	6.75		6.95		6.95			6.65		6.65
25		9.30	8.60		9.00		7.60			7.60		8.60
26		1.45			4.15		1.85			2.15		4.65
27		dry	5.70		6.20		6.30			9.55		9.80
						1972						
1		6.25	3.65		3.85	4.45			5.35		5.05	
2		4.15	3.15		3.45		2.15		2.95		3.15	
3		rep.			7.00	7.80			8.90		8.40	
4		6.90	6.30		4.10		4.60		6.70		6.20	
5			3.80		4.00							
6		6.10	2.00		3.10		4.40		3.90		2.20	
7		8.20	8.10		6.30		5.40		6.30		6.30	
8		7.20	3.70		4.10		7.40		4.80		4.60	

Table C2 (continued)

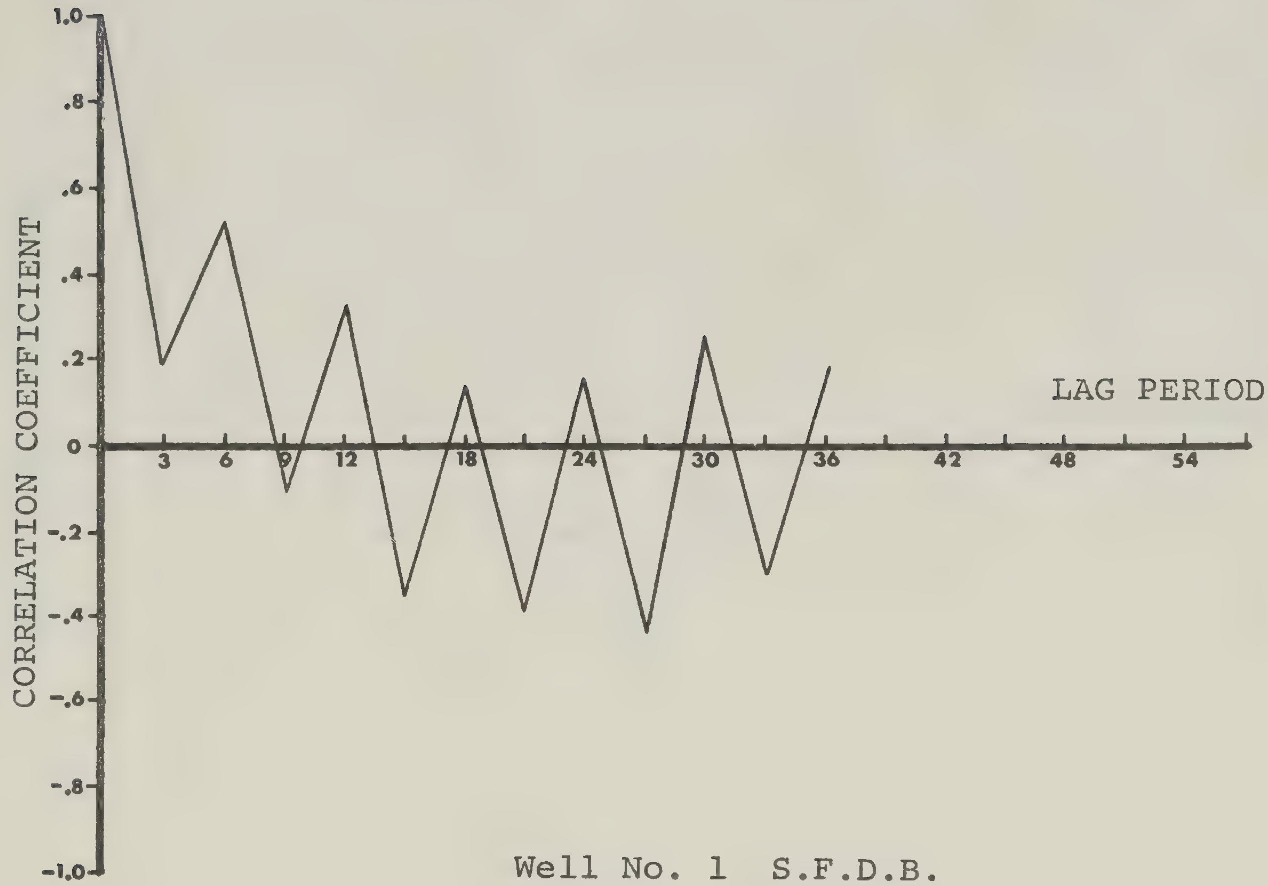
Well No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
9		6.35	3.65		3.35		2.15		2.05		3.15	
10					4.50		4.30		4.30		4.70	
11		3.55	4.15		3.55		5.15		7.75		6.65	
12		6.55	2.15		3.25		2.05		2.95		3.75	
13		frz.	2.15		2.55		2.15		2.15		2.75	
14		6.40	5.70		4.20		3.50		8.20		7.70	
15		dry	12.65		dry		dry		dry		dry	
16		4.90	2.80		3.10		3.80		4.00		4.40	
17		8.10	5.30		4.90		7.90		7.80		5.80	
18		11.15	8.35		6.25		4.85		5.05		5.45	
19		4.70	2.90		3.90		3.90		4.20		4.10	
20		8.80	2.20		3.20	4.20			6.60		6.00	
21		10.35	8.95		8.65	8.15			9.05		9.15	
22		dry	8.00		5.20	6.50			10.30		10.20	
23		6.90	.90		2.50		3.10		2.60		1.90	
24		6.05	4.35		4.75		5.45		6.05		5.95	
25			8.60		7.70		7.90		8.60		9.00	
26		4.75	3.45		3.35		4.75		4.05		4.65	
27		10.10	7.10		5.50		6.30		8.30		7.10	
						1973						
1	4.85		4.85		5.45		5.15					
2	2.95		2.45		des.							
3	8.40		8.30		8.30		8.80					
4	5.50		5.50		5.60		5.70					
5	6.30		5.50		5.50		5.50					
6	3.70		2.80		3.90		3.90					
7	6.80		6.30		6.10		2.80					

Table C2 (continued)

Well No.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
8	4.30		3.70		des.							
9	4.55		3.05		2.65		2.45					
10	5.50		4.70		4.60		4.40					
11	4.55		4.15		5.65		4.55					
12	4.75		5.45									
13	3.35		1.65		2.85		1.55					
14	7.10		6.20		6.40		7.70					
15	dry		11.85		dry		dry					
16	3.90		3.00		des.							
17	6.50		6.10		5.70		6.60					
18	5.75		5.15		5.95		5.35					
19	3.50		3.70		4.40		2.40					
20	5.20		4.85		4.95		5.60					
21	9.75		9.95		10.15		8.05					
22	frz.		7.20		des.		9.45					
23	3.60		2.40		3.90		3.70					
24	5.95		5.75		5.65		5.65					
25	9.40		frz.		9.40		7.80					
26	3.35		3.35		des.							
27	6.90		6.70		6.70		7.10					

APPENDIX D

This appendix contains the correlograms for the wells in the South Fincastle Drainage Basin and the MacLaine Drainage Basin.



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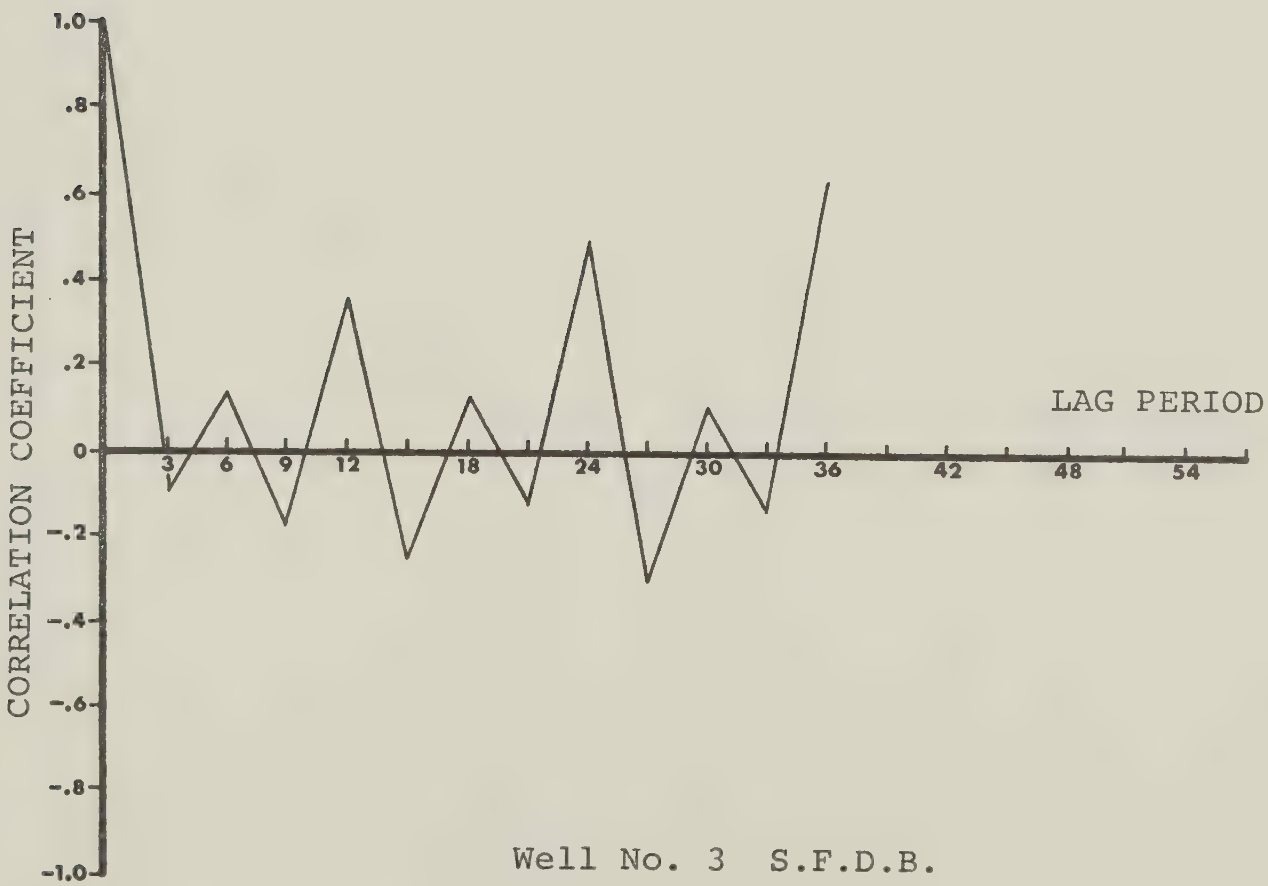

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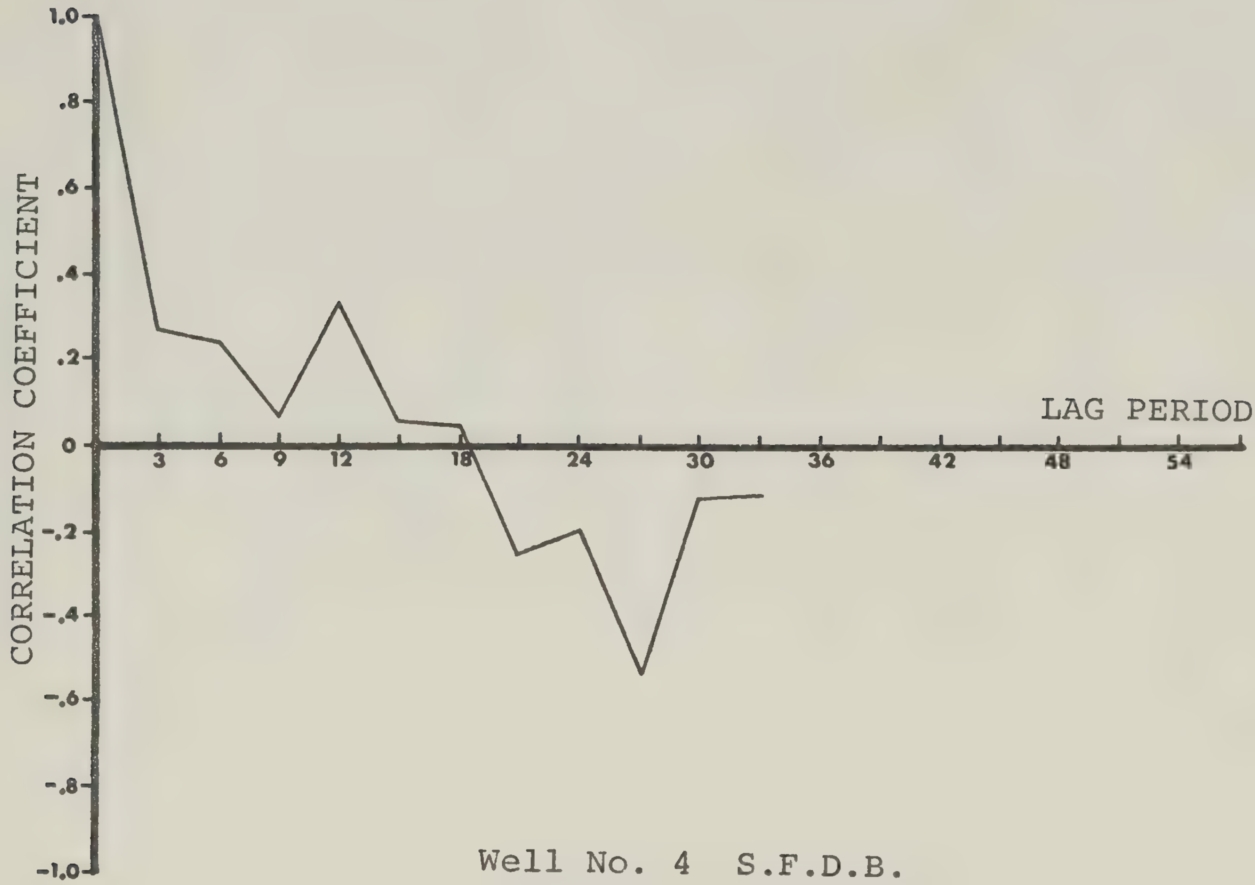

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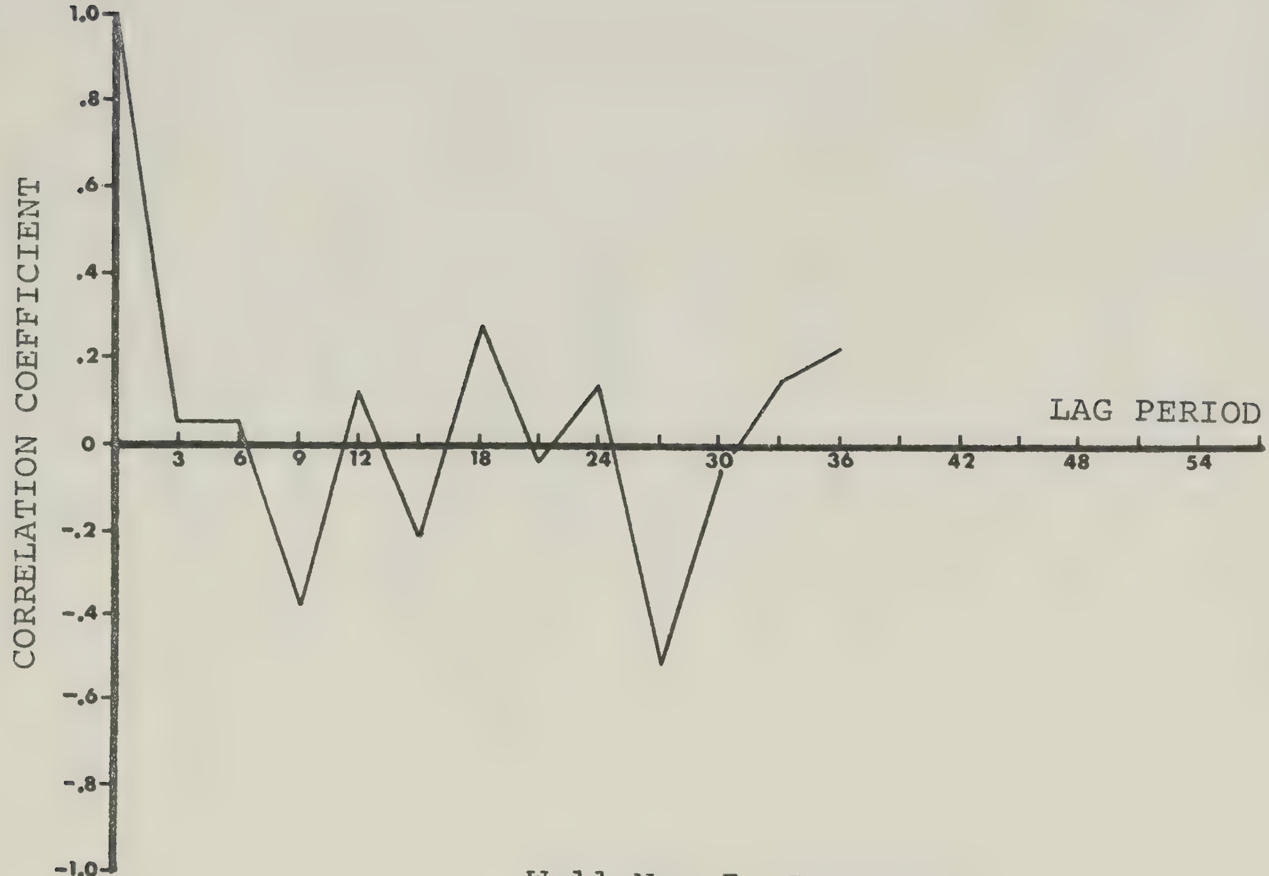
Well No. 5 S.F.D.B.



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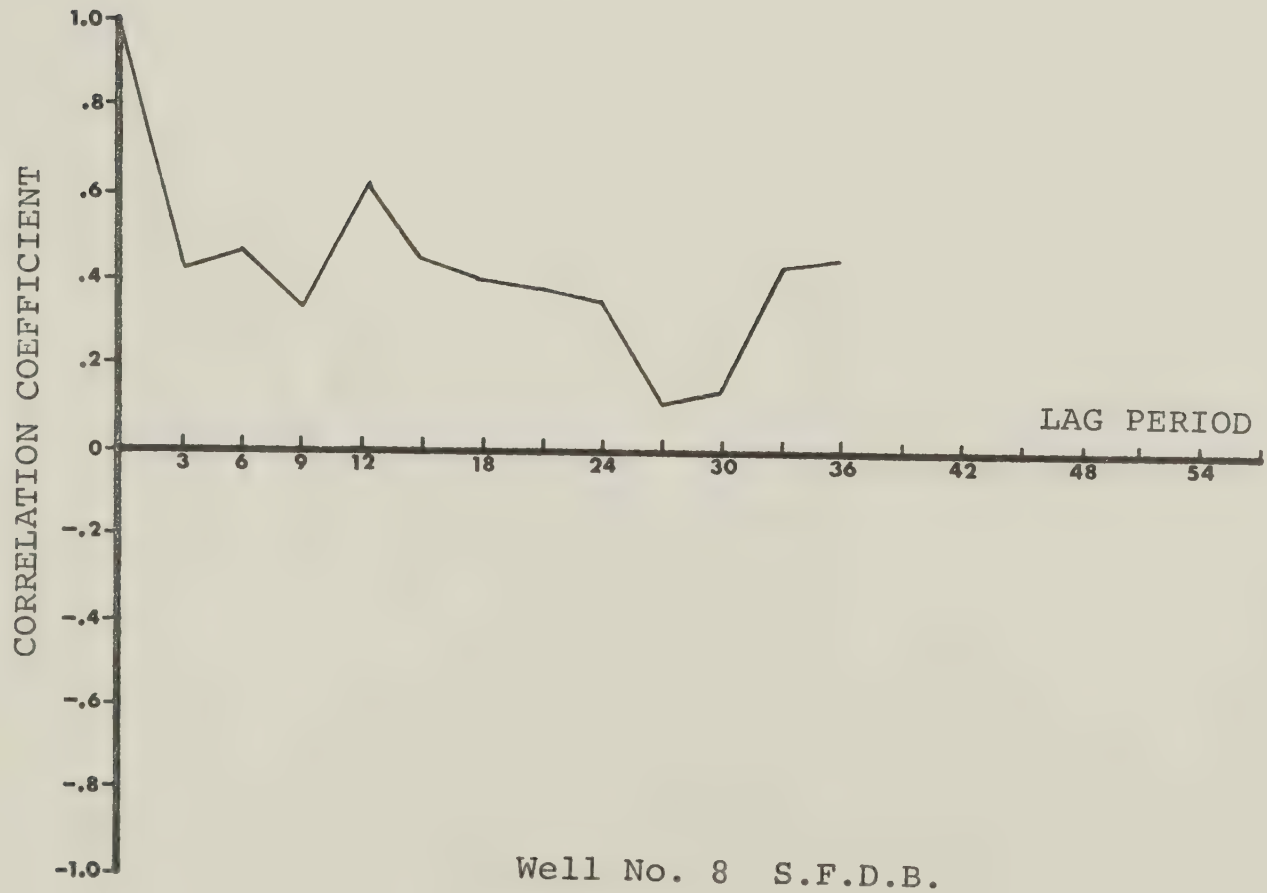
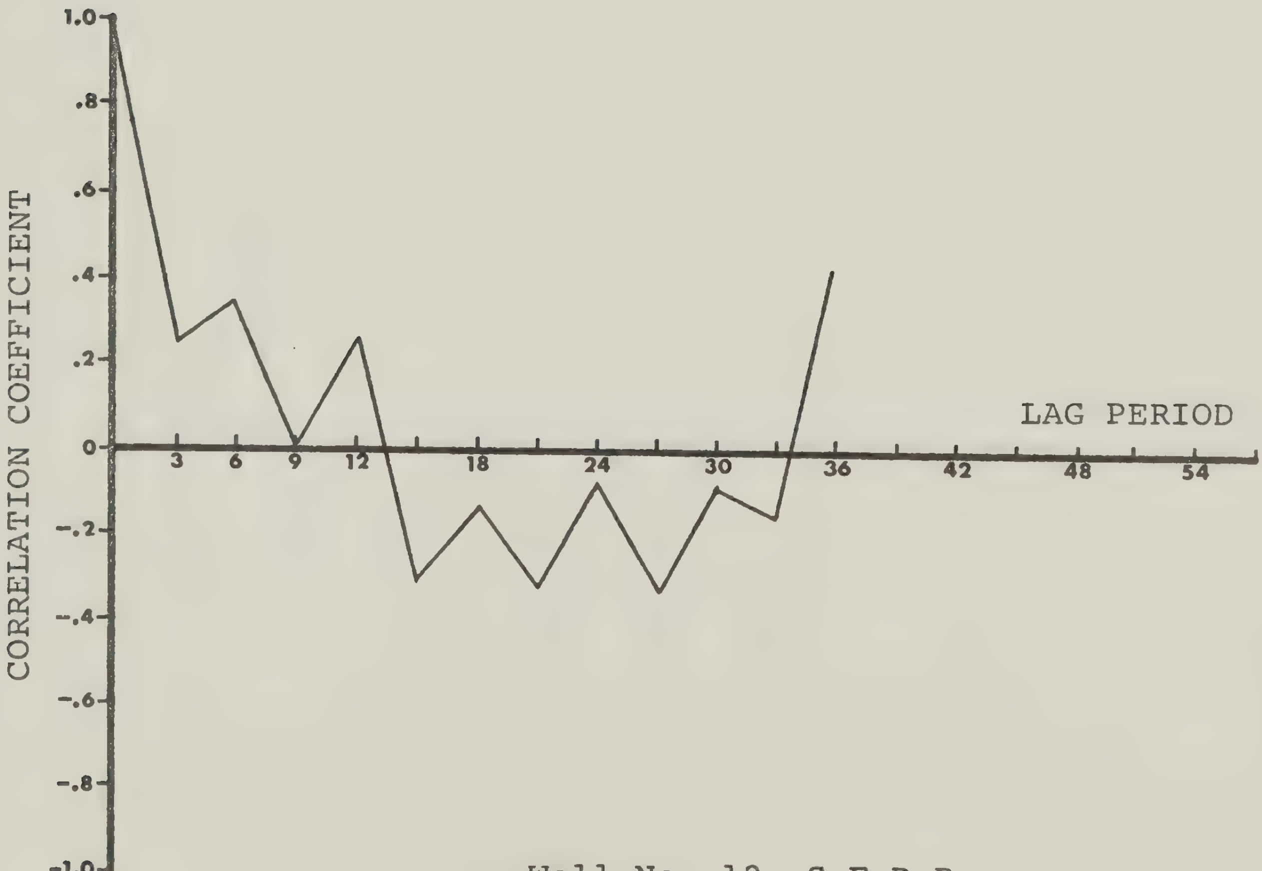


Well No. 8 S.F.D.B.

Well No. 11 S.F.D.B.



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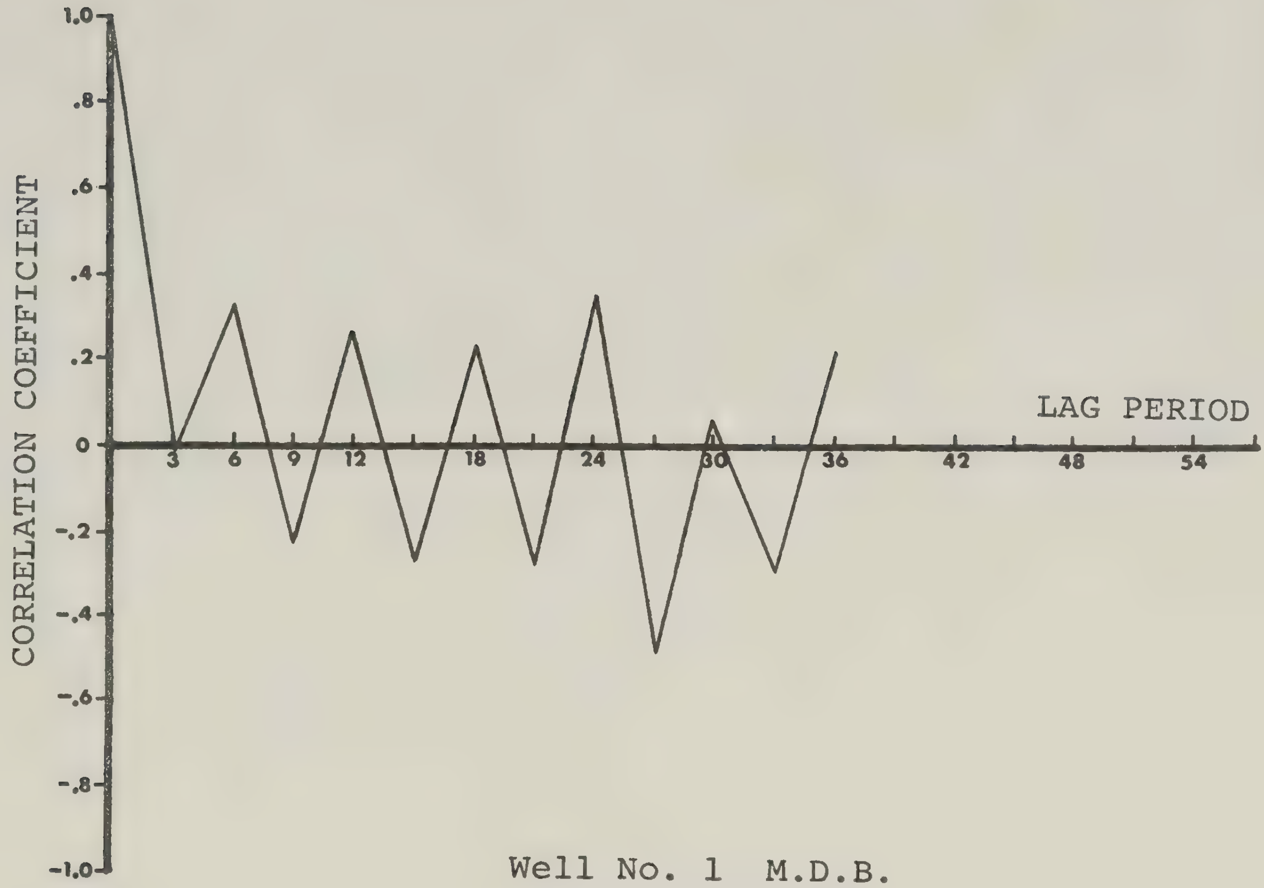

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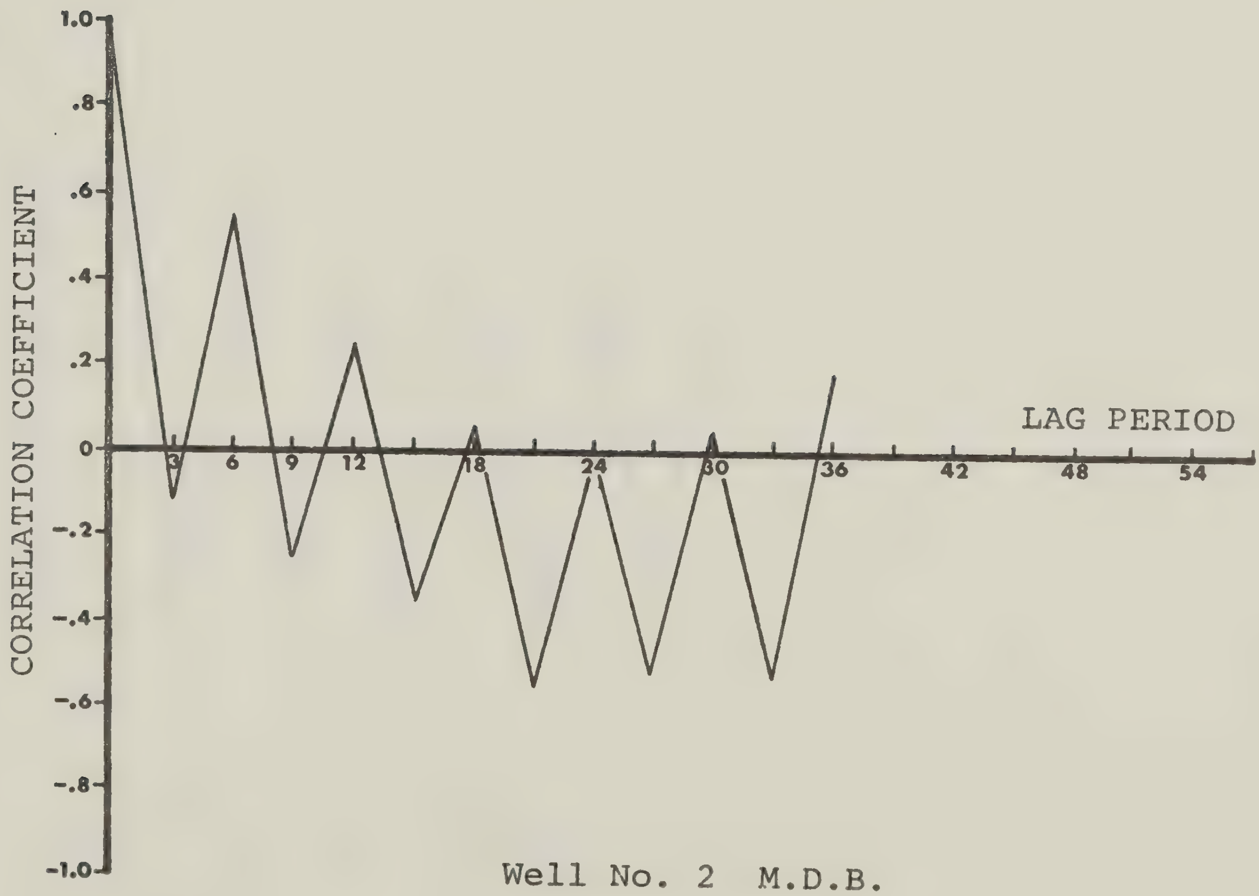
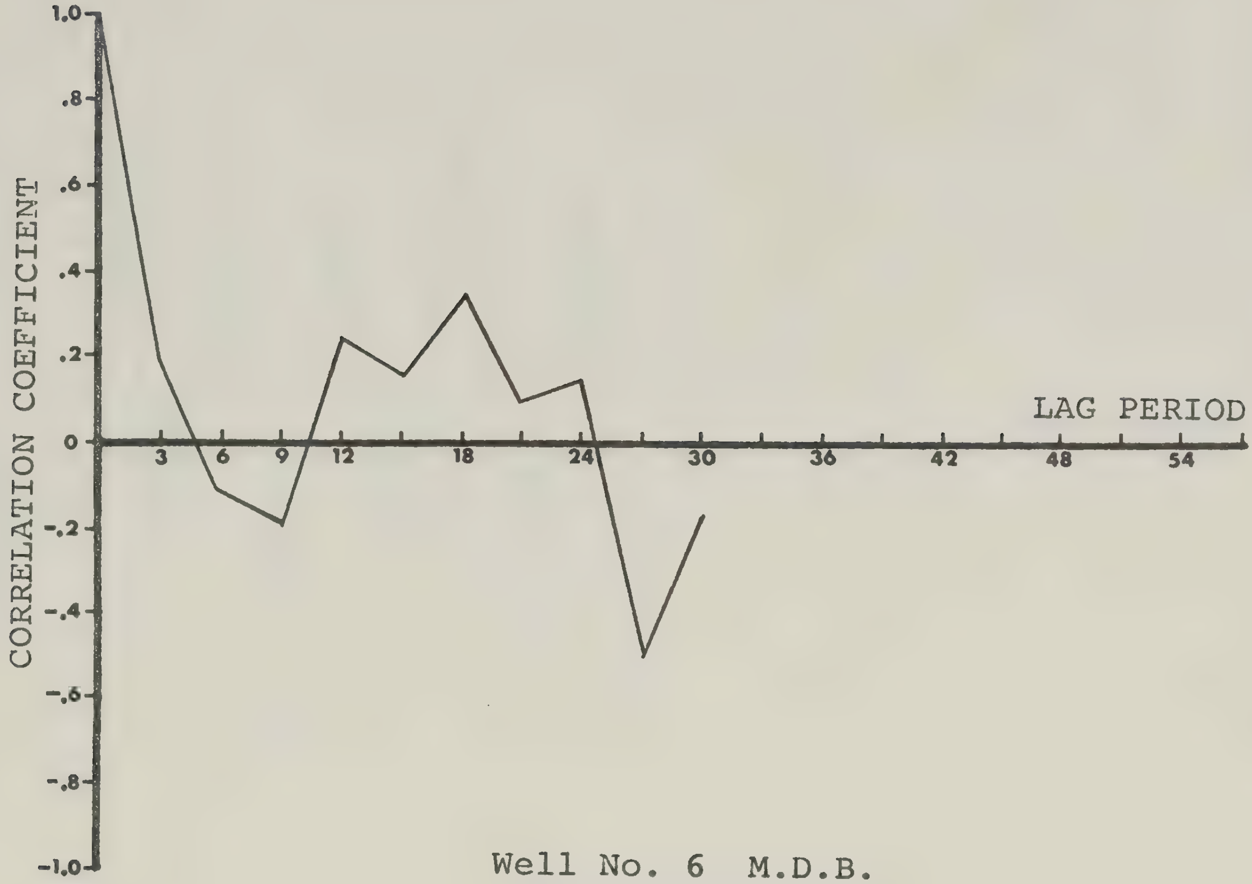


Well No. 2 M.D.B.



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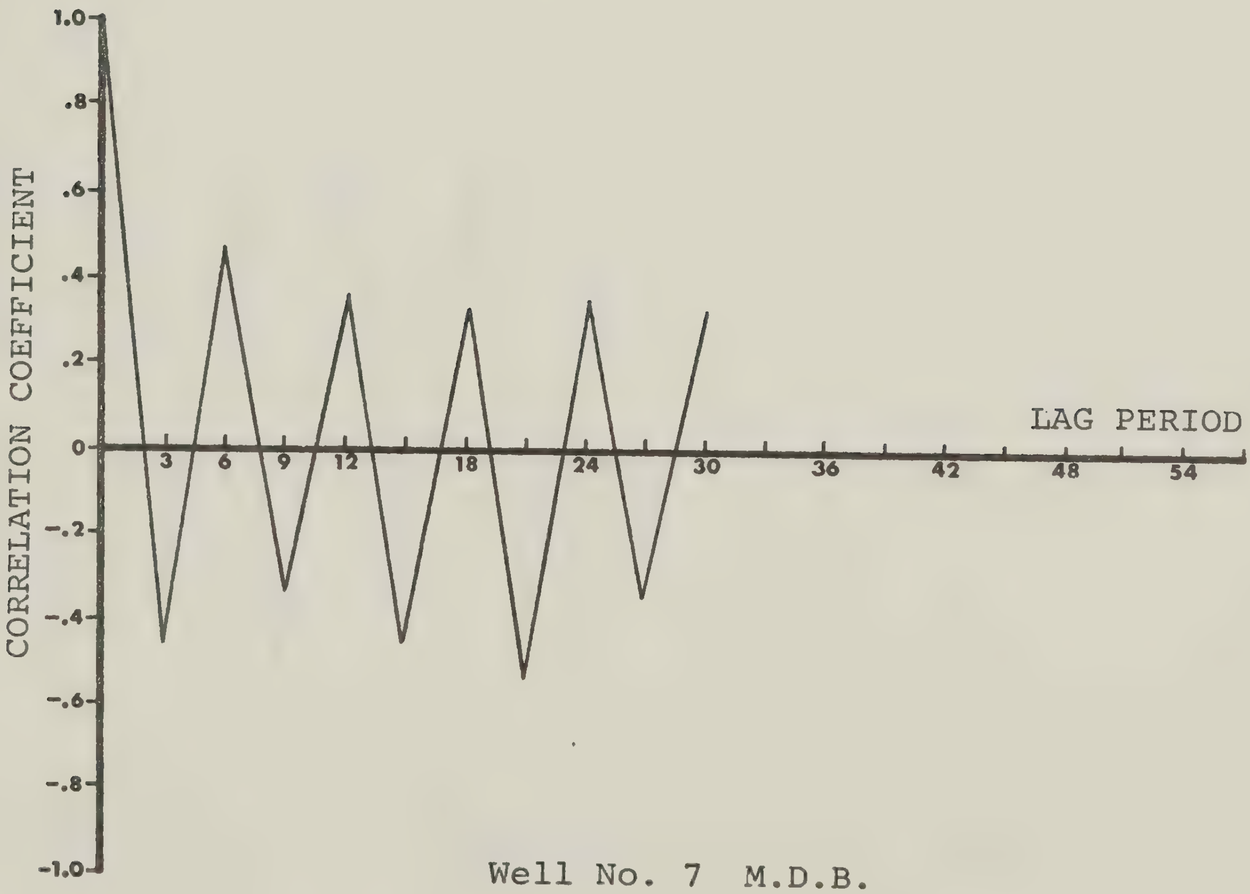
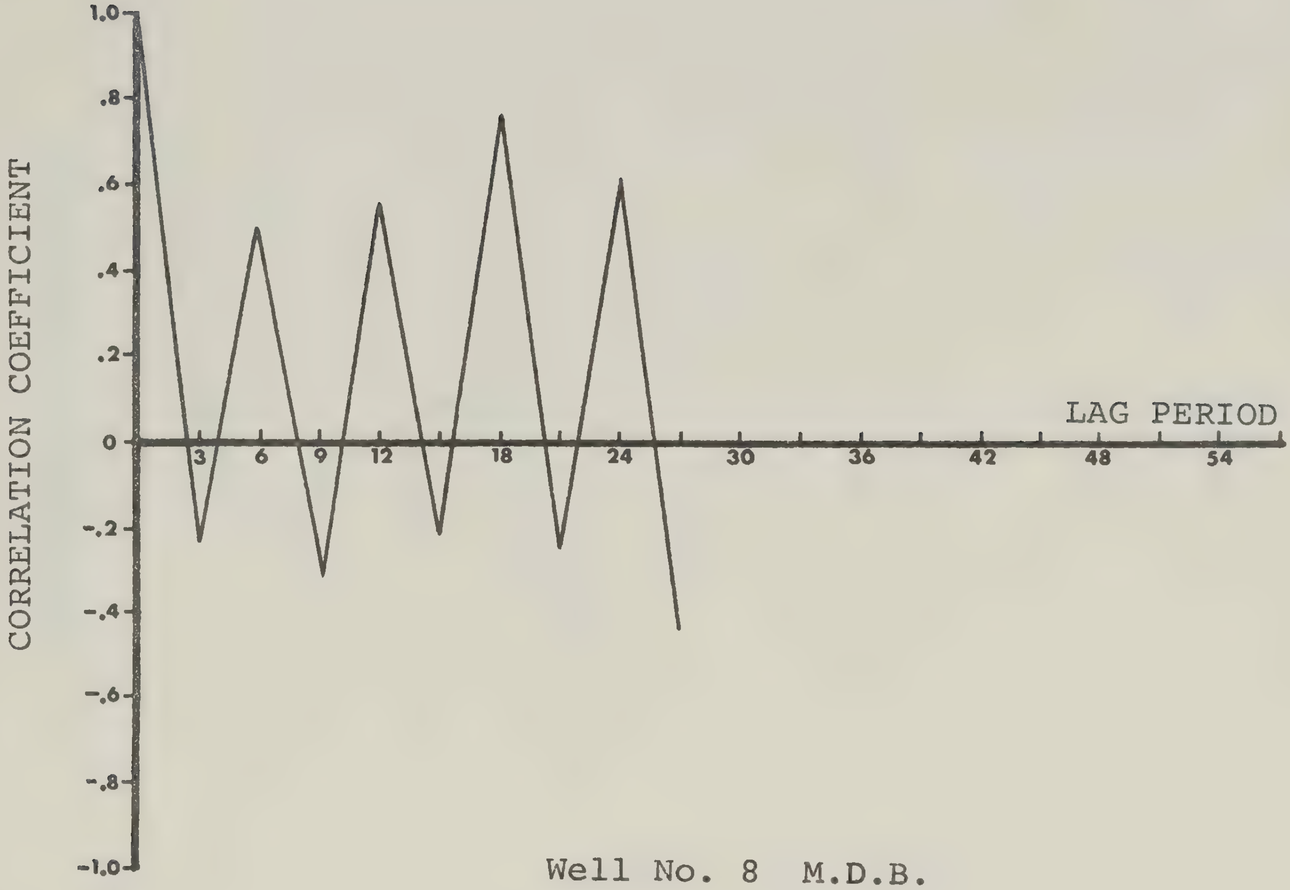


Well No. 7 M.D.B.



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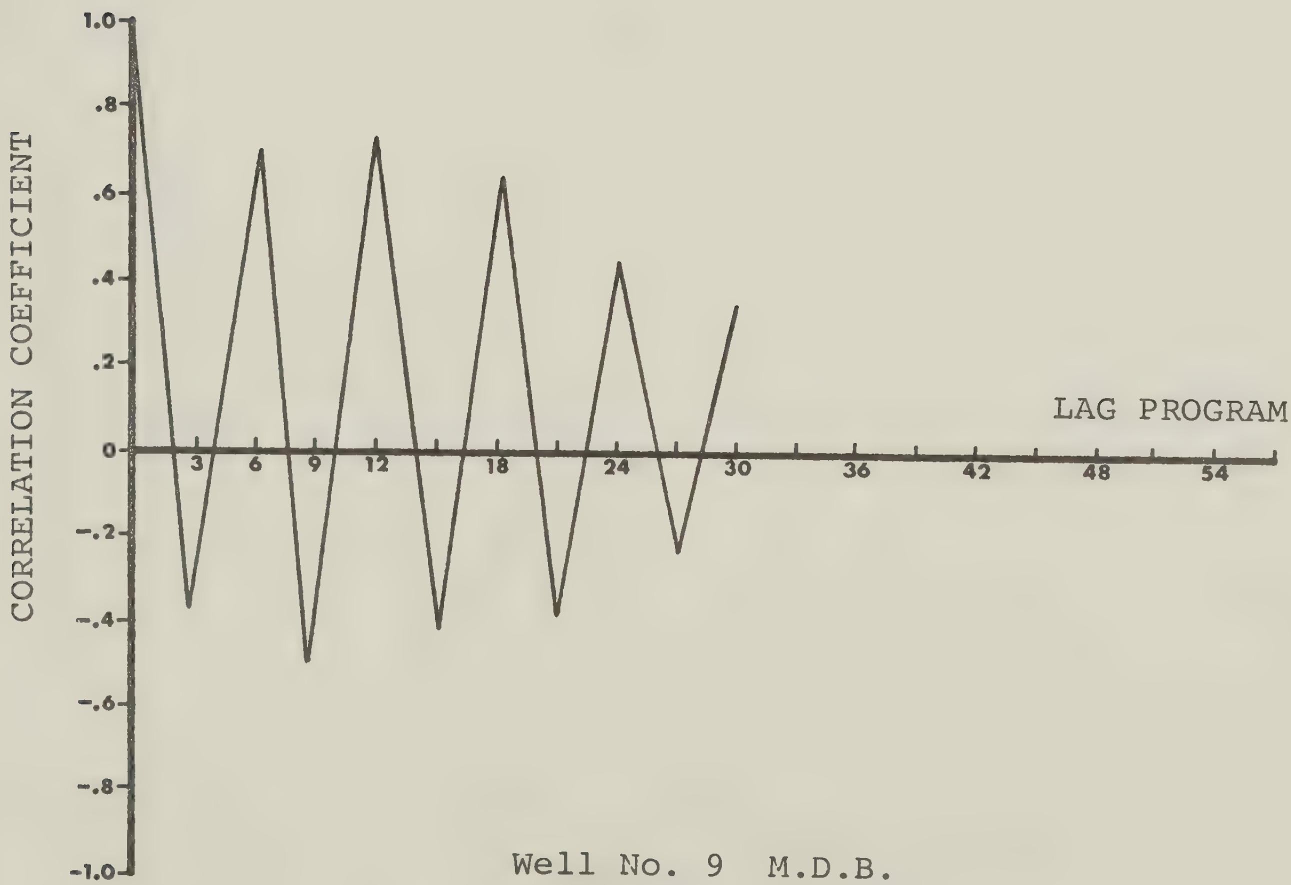

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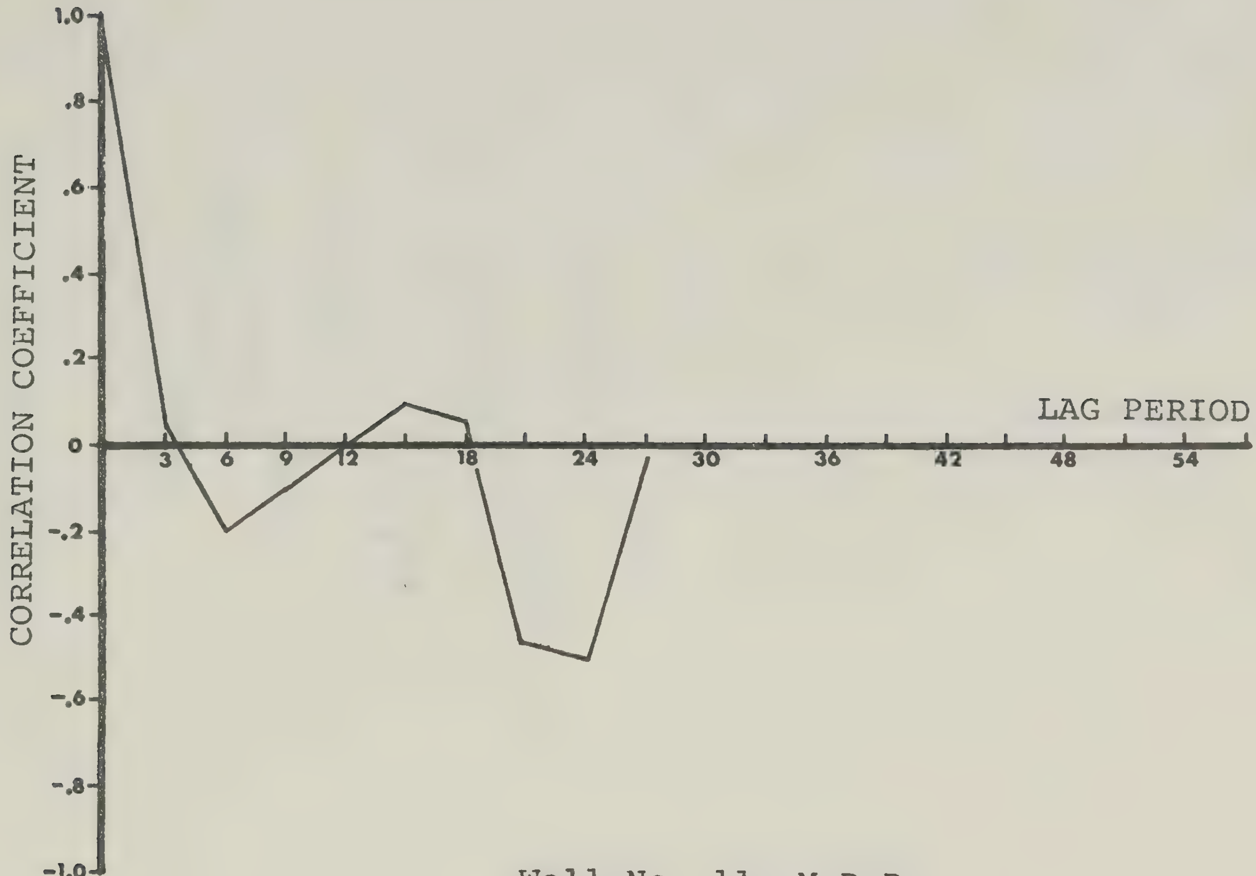

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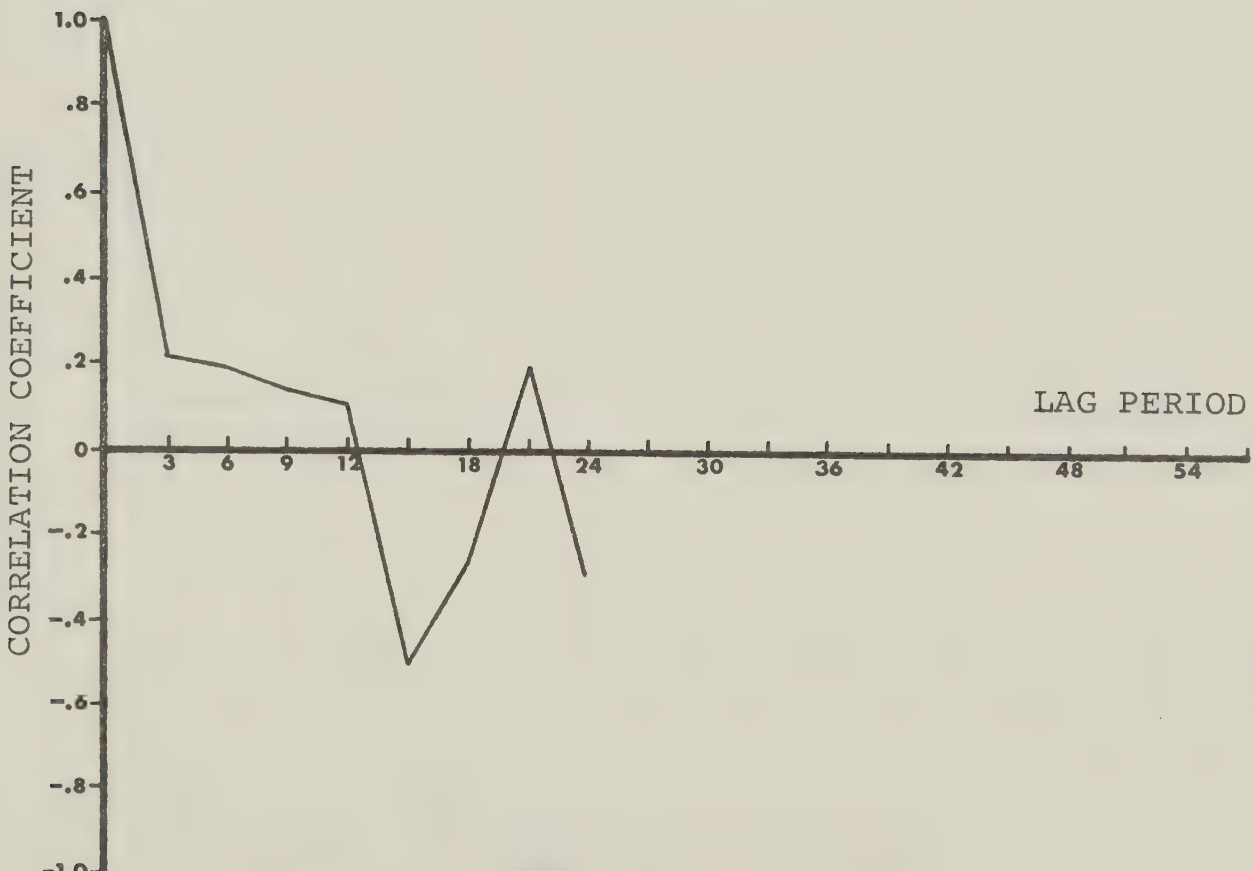

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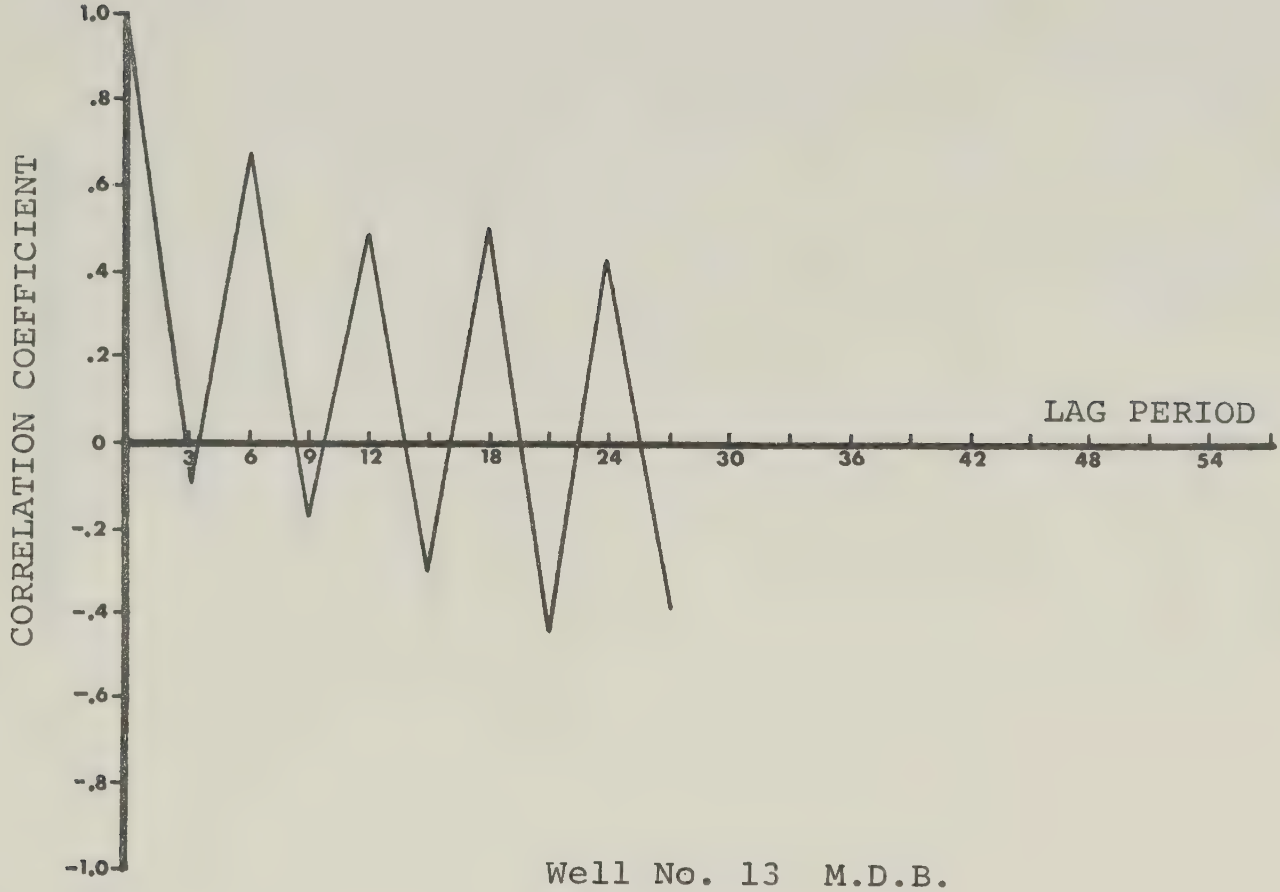

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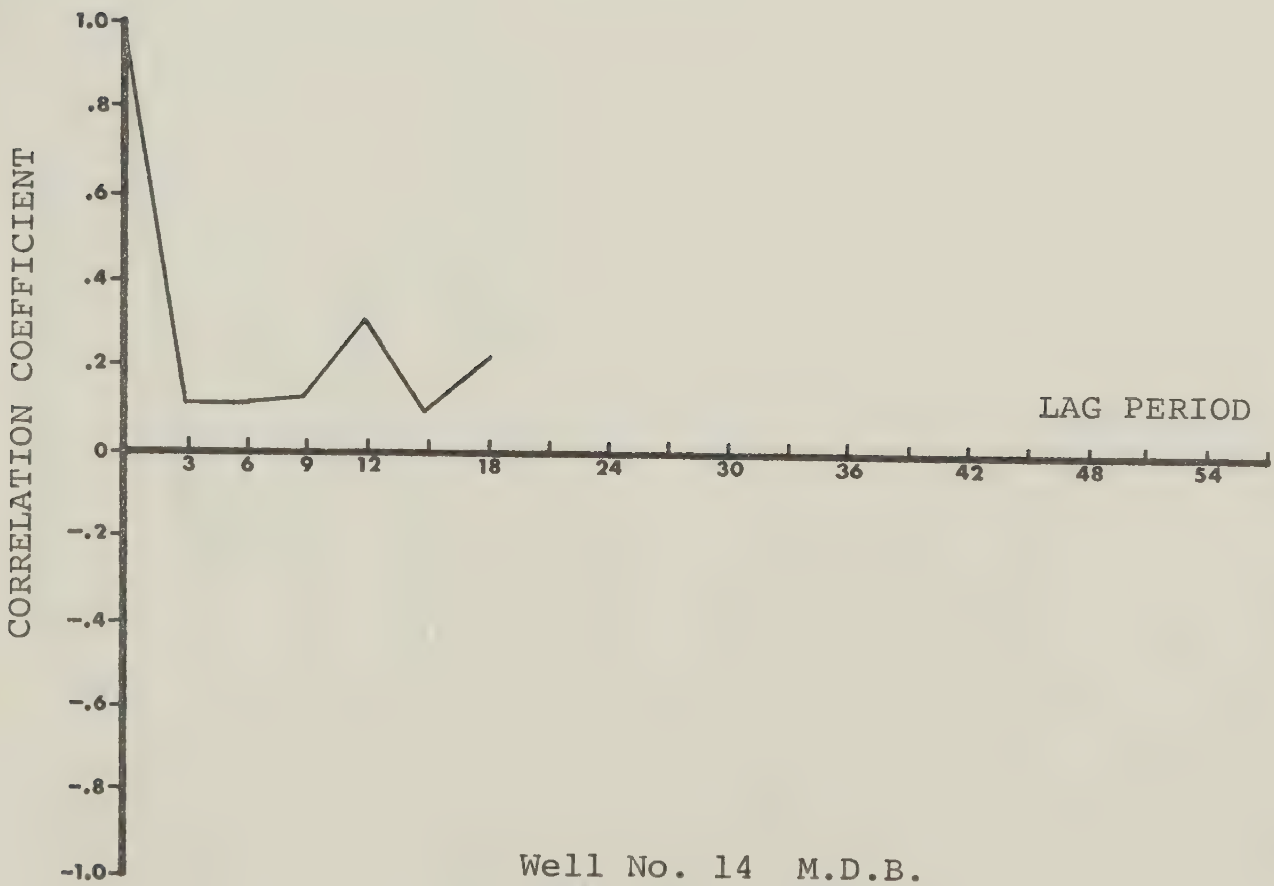

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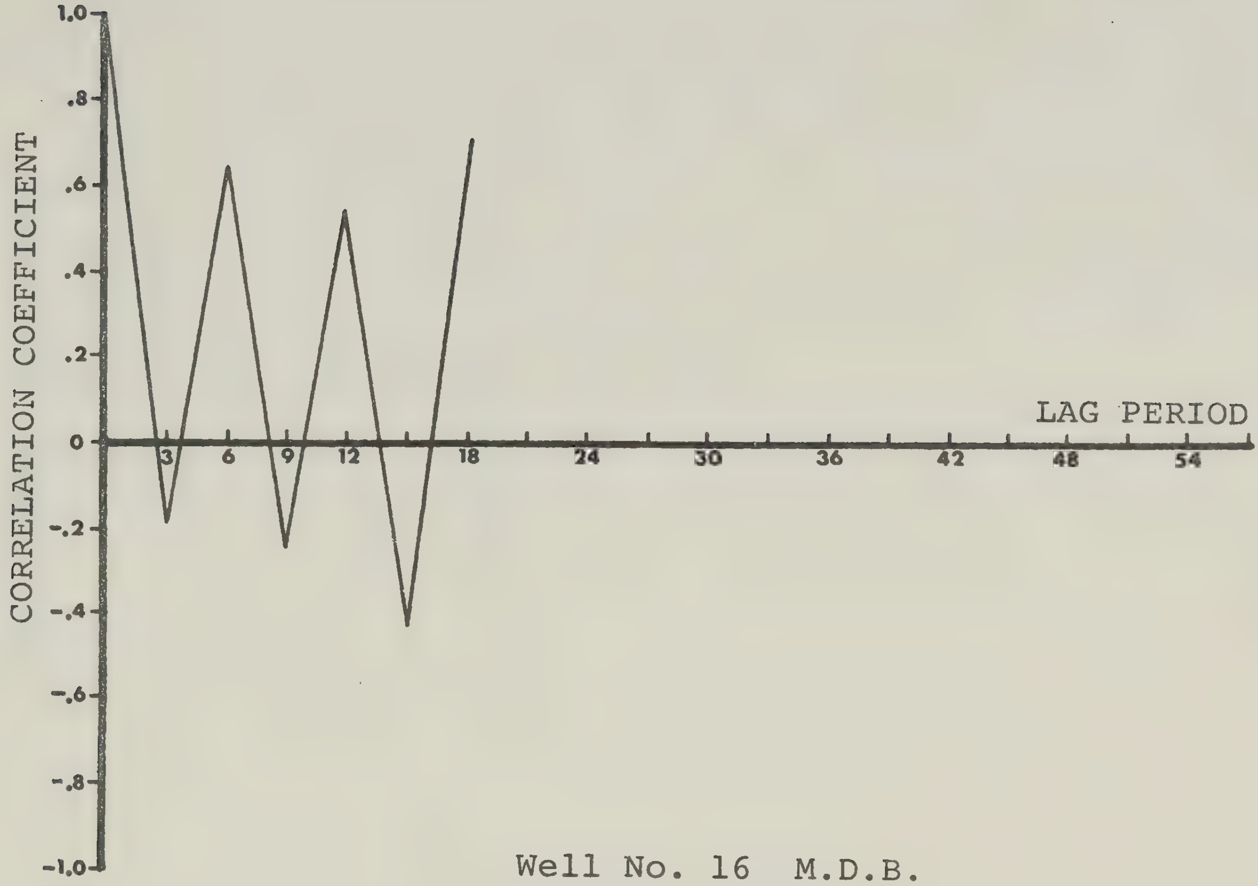

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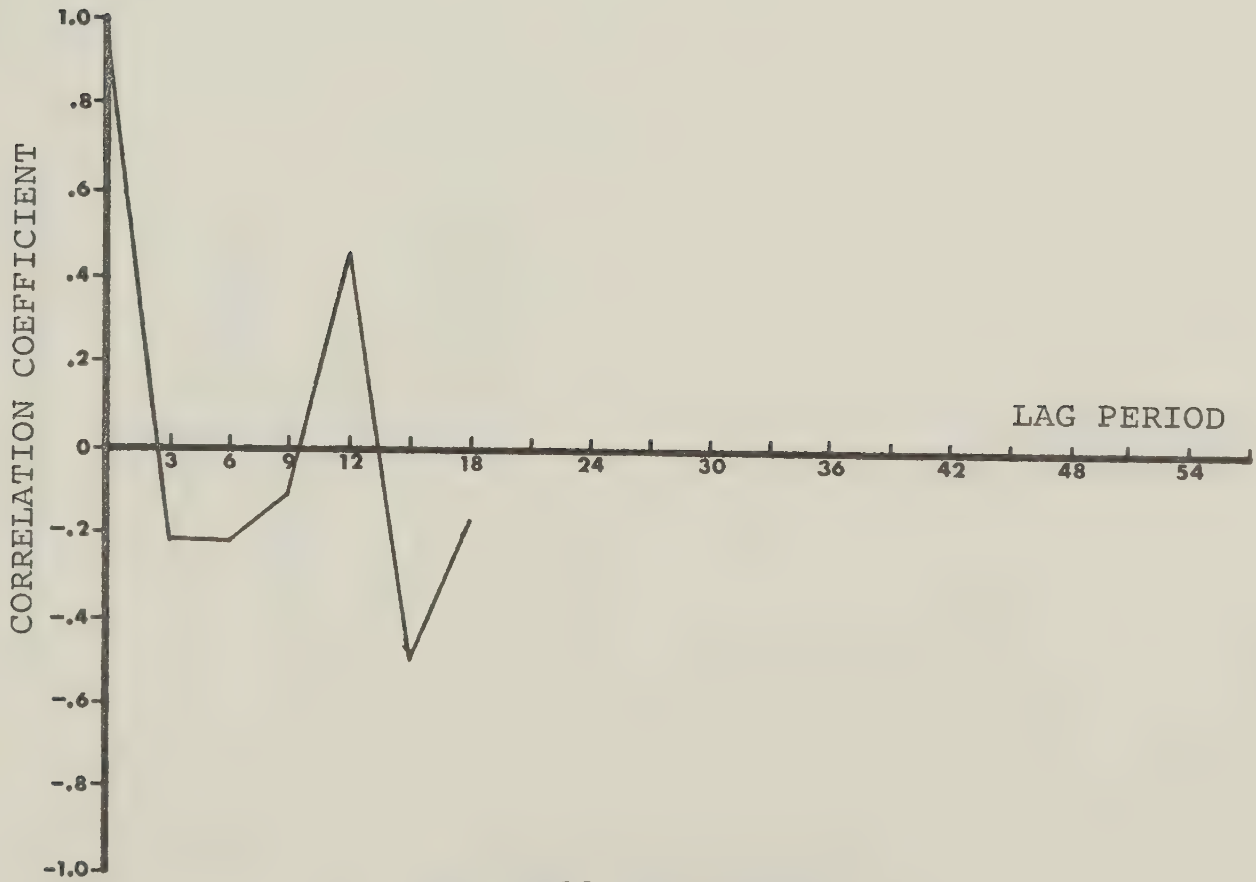

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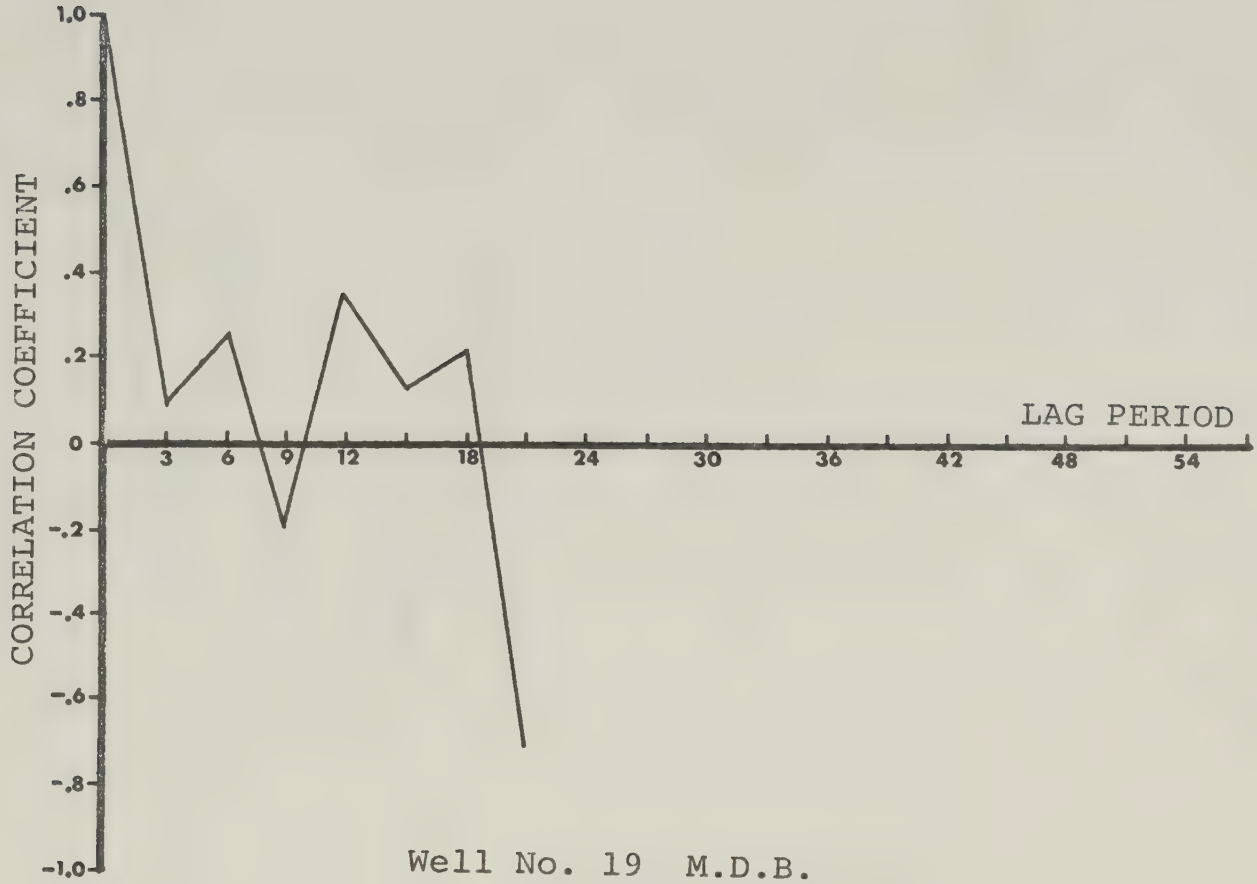

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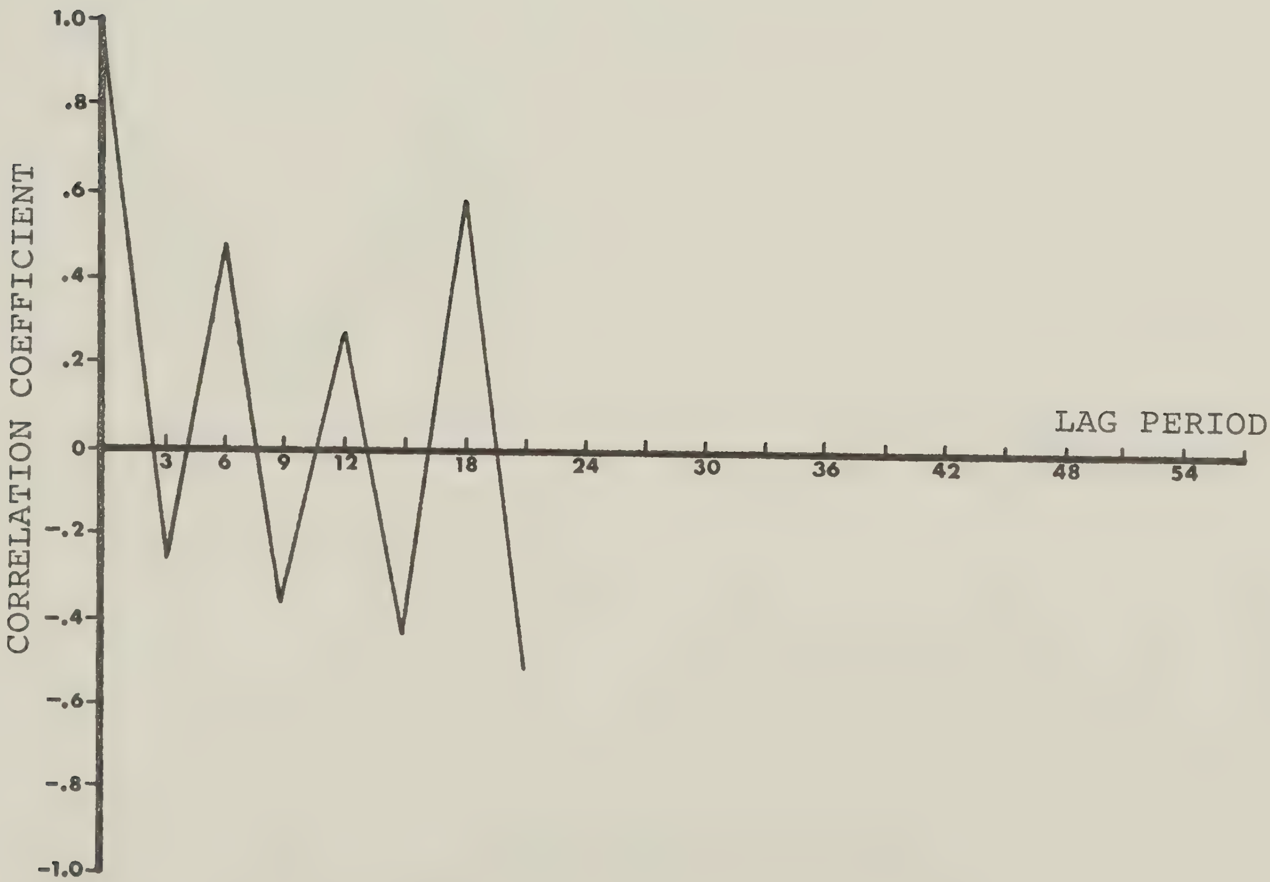
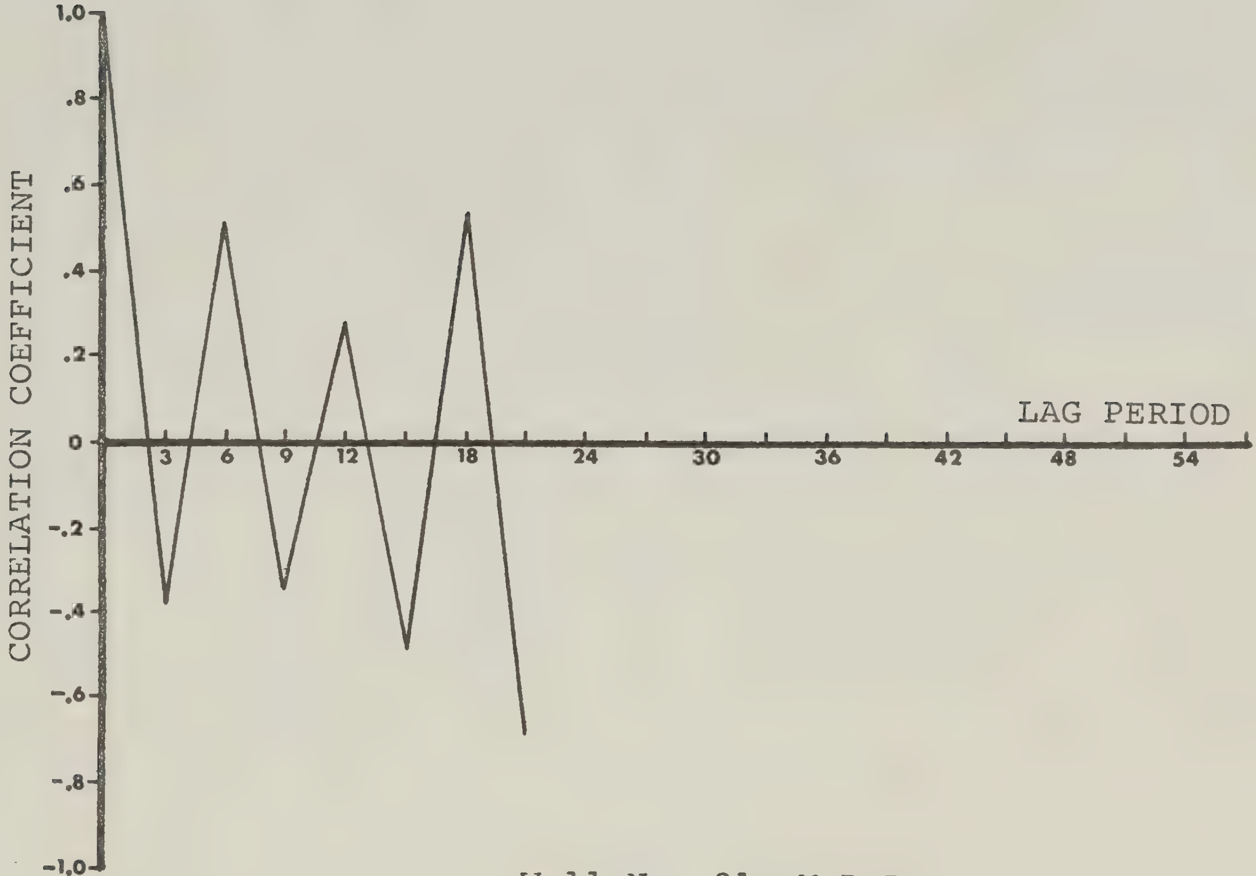
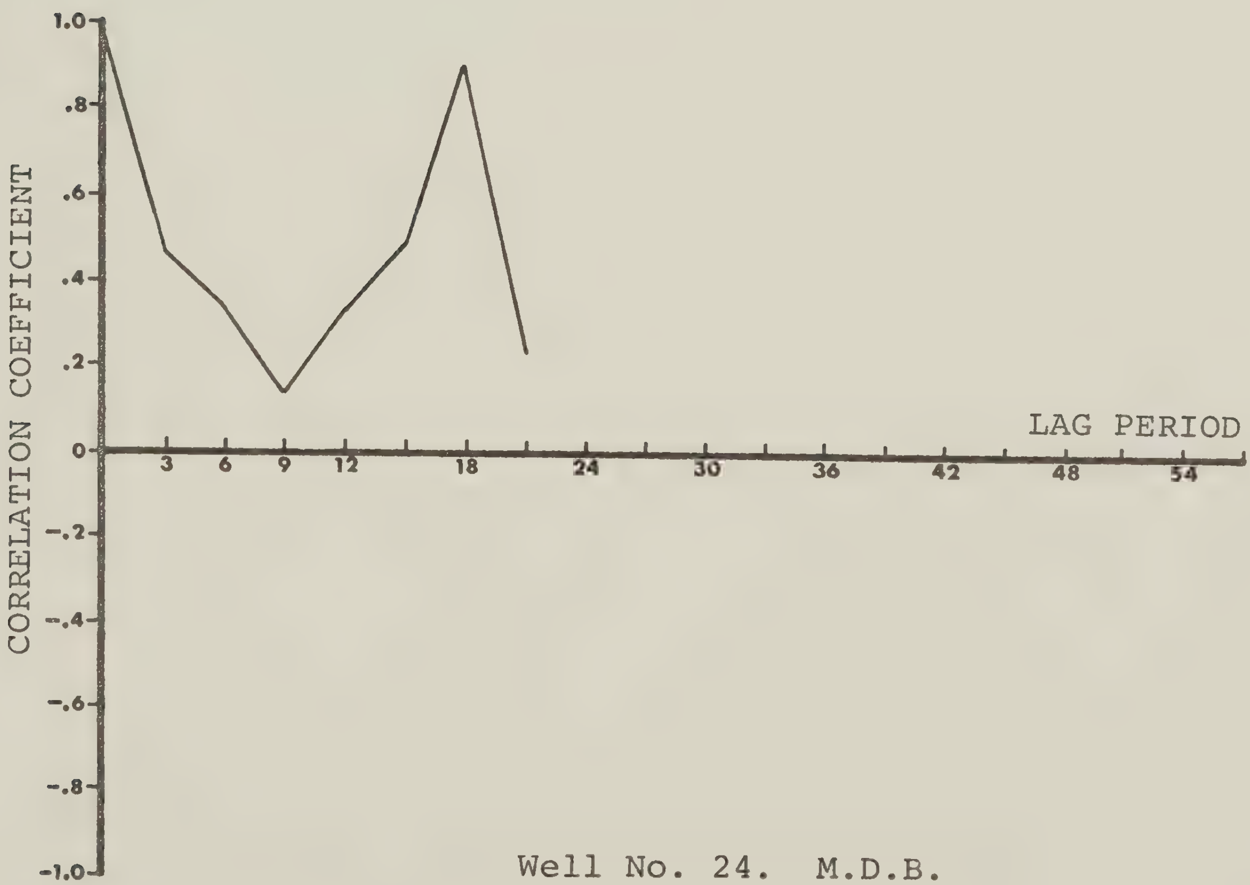


Well No. 20 M.D.B.



Well No. 21 M.D.B.



Well No. 24. M.D.B.